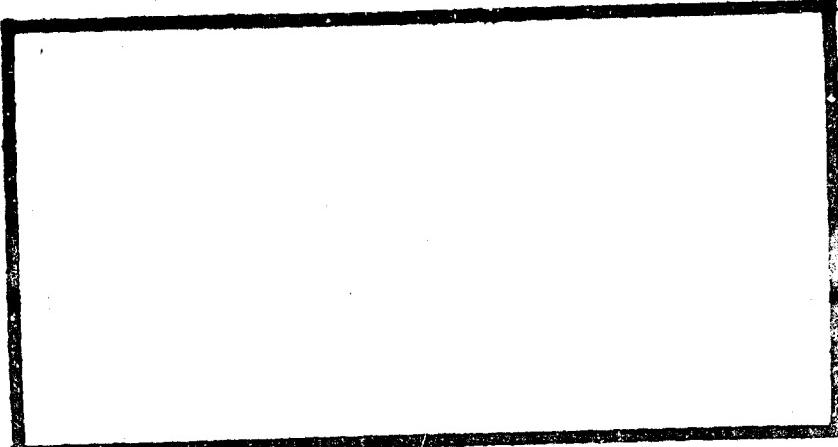
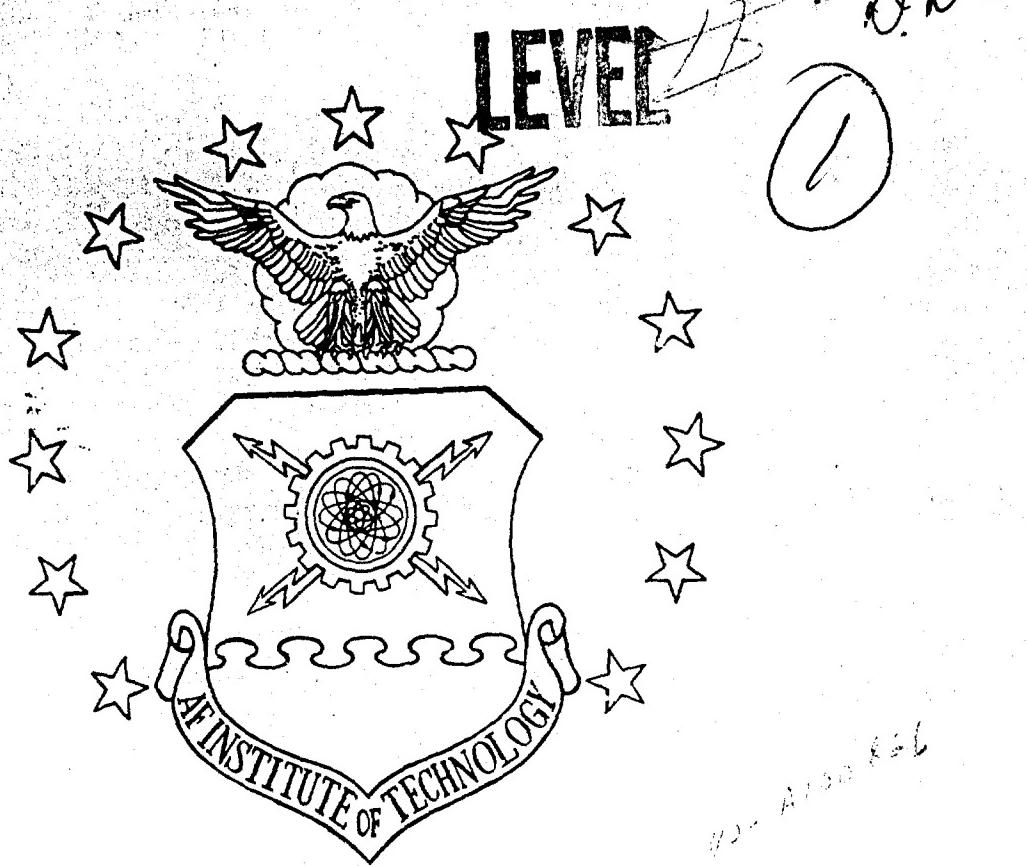


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AFIT/GE/EE/80D-15

6 THE EFFECTS OF REFRACTIVE ERROR ON  
THE DETECTION AND IDENTIFICATION OF  
SIMPLE AND COMPLEX TARGETS.

2 M.S. THESIS

(14) AFIT/GE/EE/80D-15

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(11) 100

(12) 103

Aug 27 1981

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THE EFFECTS OF REFRACTIVE ERROR  
ON THE DETECTION AND IDENTIFICATION OF  
SIMPLE AND COMPLEX TARGETS

THESIS

Presented to the Faculty of the School of Engineering of  
The Air Force Institute of Technology  
Air University

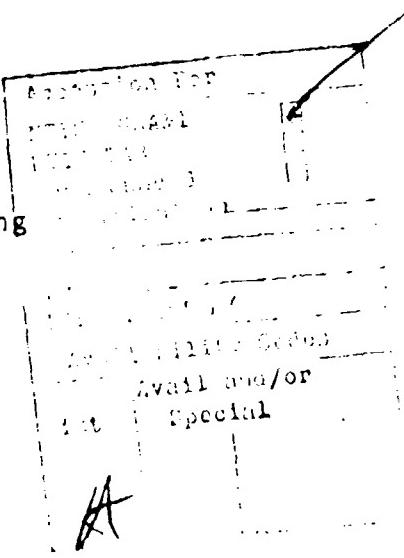
In Partial Fulfillment of the Requirements for the  
Degree of Master of Science

By

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Graduate Electrical Engineering

December 1980



## Preface

The research for this thesis was accomplished at the AF AMRL Aviation Vision Lab. It used the concept of contrast sensitivity to show the effect of refractive error on visual process. It also covered a small part of the effects of low luminance conditions.

I would like to thank Dr. Art Ginsburgh for all his help, ideas, and comments; and Dr. Matt Kabrisky and Dr. Lynn Wolaver for all their comments. I would also like to thank Steve Fullenkamp and Penny Konys for their time, understanding, and help, and a special thanks to Jim Hart for all the hours he spent as a subject.

Julie B. Cohen

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## Abstract

The effect of refractive error on the detection and identification of simple and complex targets was studied. Contrast sensitivity to sine-wave gratings of spatial frequencies from 0.61 to 22 cycles per degree with induced refractive errors of 0, +1, +2, +3, +4, +5, and +6 diopters were measured. Objective subject accommodation measurements were determined. The contrast needed to detect and identify Snellen letters and aircraft was also measured at the same levels of refractive error. In addition, some measurements were accomplished with reductions in the average luminance of 6 foot lamberts by factors of 10, 100, and 1000.

The Effects of Refractive Error on the  
Detection and Identification of Simple and Complex Targets

I. Introduction

Purpose

The purpose of these experiments was to determine the effects of refractive error on visual target acquisition. This was done using a relatively new concept in vision measurement - contrast sensitivity.

It is known that the standard eye test using Snellen letters does not adequately test all aspects of vision (Ref 1). One parameter which is not measured by Snellen letters is contrast sensitivity. A person can have 20/20 vision, and yet not have the same capability to identify targets at low contrast levels as a person with 20/30 vision. This ability to detect and identify targets at low contrast has important implications in the area of target detection and identification since many Air Force tasks involving target acquisition are done under low contrast conditions.

This experiment measured the threshold perception needed to detect sine-wave gratings, and to detect and identify letters and airplanes over a range of spatial frequencies from .5 to 22 cycles per degree. The measurements were taken while viewing the target through various lenses ranging in strength from +1 to +6 diopters. The subject's accommodation was also measured to determine

the subject's accommodative response. In addition, some measurements determined the effects of low luminance conditions combined with refractive error.

### Background

Contrast Sensitivity. In general, contrast is a measurement of the difference in luminance between an object and its background. The contrast measurement used was:

$$C = \frac{L_{Max} - L_{Min}}{L_{Max} + L_{Min}} \quad (1)$$

where C is contrast and  $L_{Max}$  and  $L_{Min}$  are the maximum and minimum luminance values. This equation was used because the average luminance remains constant, therefore the eye does not have to adapt to different luminance conditions as contrast measurements are made. Contrast sensitivity, which is the reciprocal of threshold contrast, is a measure of the level of contrast needed before an object can be detected or identified from the background. The contrast sensitivity needed by the human visual system to detect an object as a function of spatial frequency is given by the contrast sensitivity function (CSF).

One method of determining a person's CSF is to have him view sine-wave gratings at various spatial frequencies and adjust the contrast until the grating is just visible. In this way, the contrast needed to just detect the grating can be determined for any spatial frequency. Figure 1 shows a sine-wave grating with the spatial frequency increasing

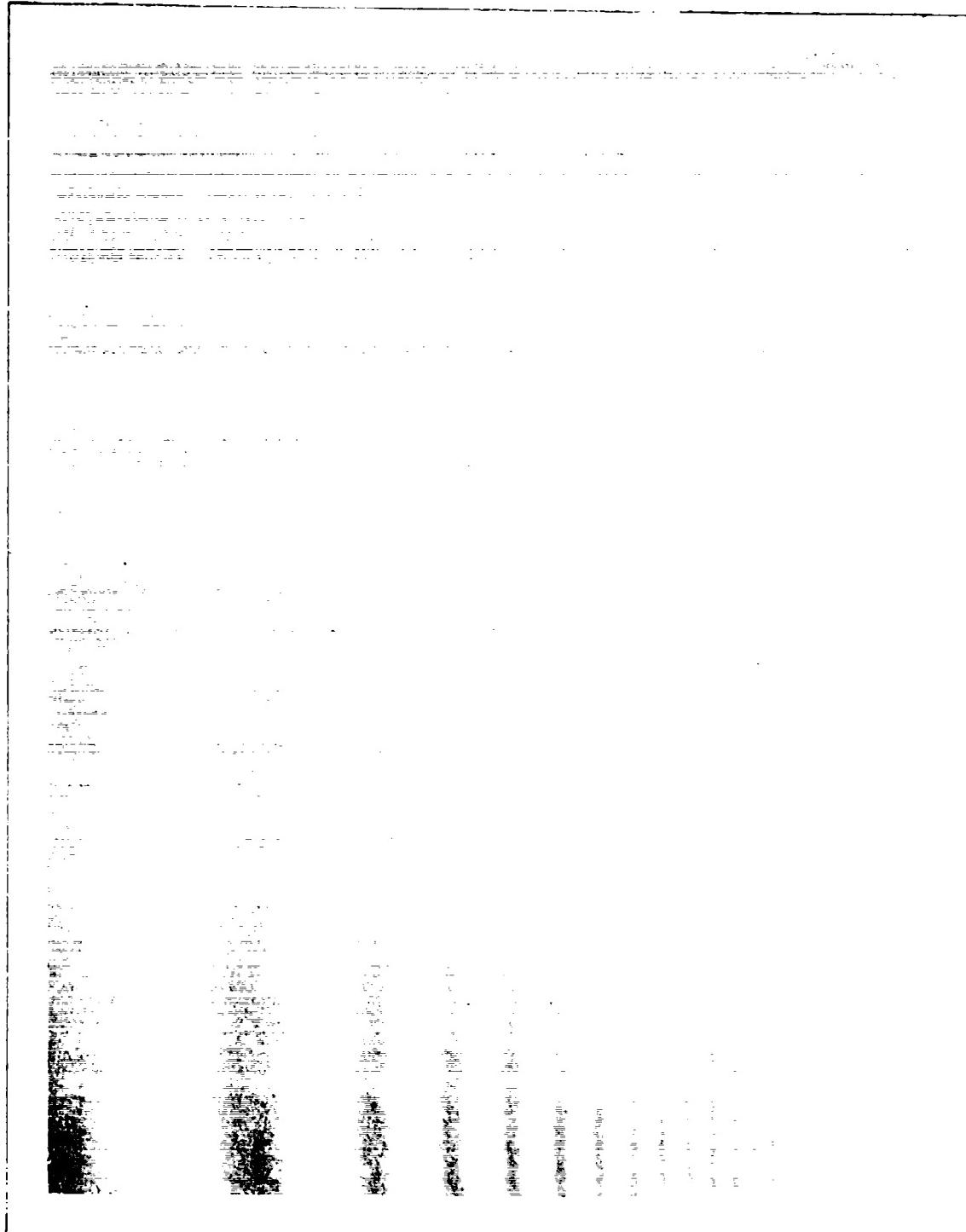


Figure 1. Sine-Wave Grating with Spatial Frequency and Contrast Sensitivity Increasing Logarithmically  
(Ref. 1:134)

logarithmically from left to right and the contrast decreasing logarithmically from top to bottom. Note that less contrast is required to see the middle spatial frequencies. A typical CSF also reflects this fact, as shown in Figure 2.

Many vision experiments have measured the CSF using sine-wave gratings. Some early investigations in this field done by Campbell and Green included the effects of refractive error (Ref 2). The accommodative response to sine-wave gratings has been studied by Charman and Tucker (Ref 3) and Owens (Ref 4). These experiments studied the basic effects of refractive error, but did not relate the response from a sine-wave gratings to those from complex stimuli such as Snellen letters and airplanes. On-going research at the AFAMRL Aviation Vision Lab is determining various aspects of threshold and suprathreshold sensitivity functions on complex target acquisition (Ref 5,6,7).

Accommodation. The lens in the human eye can change refractive power approximtely 15 diopters in young children. This ability to change refraction is known as accommodation.

The lens is a strong elastic capsule with about seventy radially attached ligaments. These ligaments attach to the ciliary muscle through two sets of smooth muscle fibers, the meridional and the circular fibers, as shown in Figure 3. It is the contraction and relaxation of these muscles which controls accommodation. The ciliary muscle is controlled mainly by the parasympathetic nervous system, but it can

## TYPICAL CONTRAST SENSITIVITY CURVE

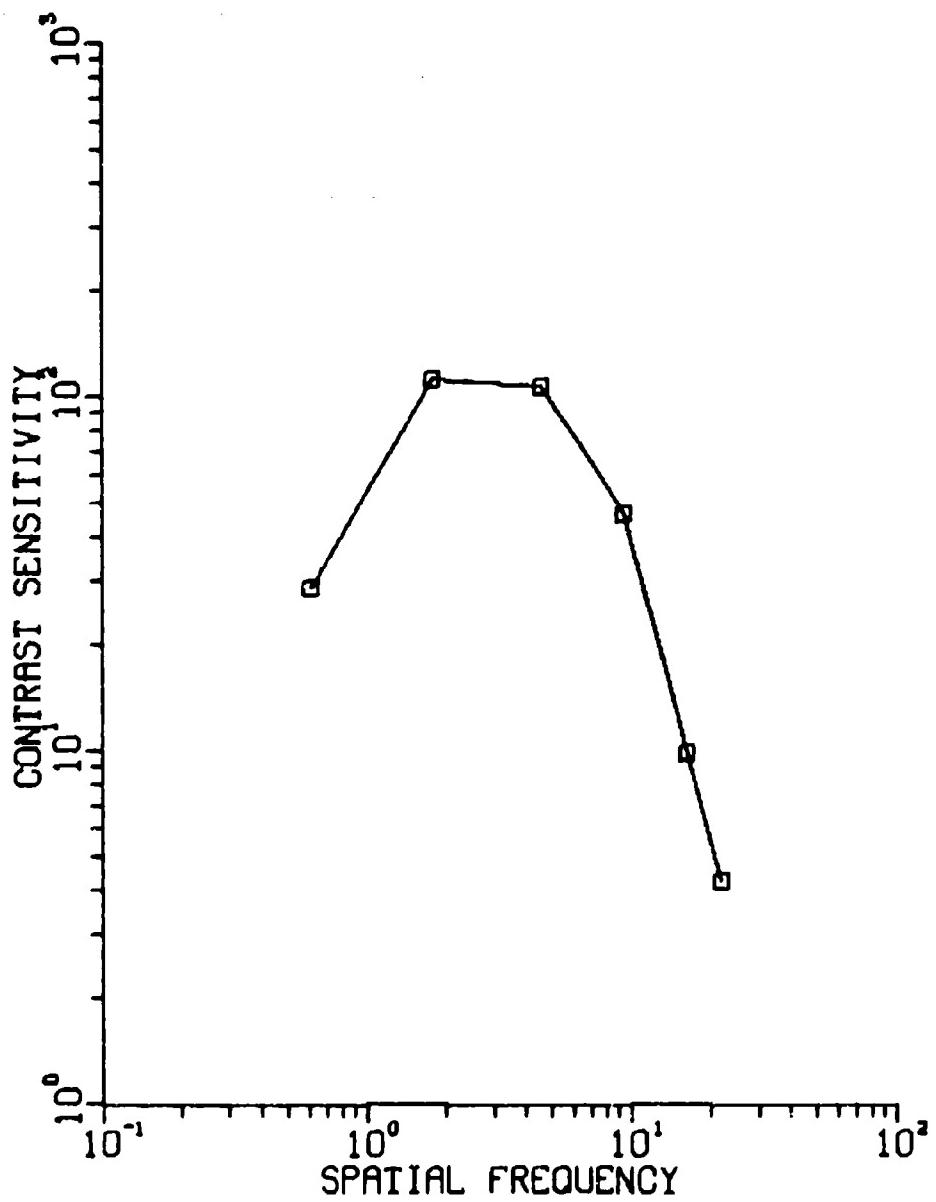


Figure 2. Typical Contrast Sensitivity Function

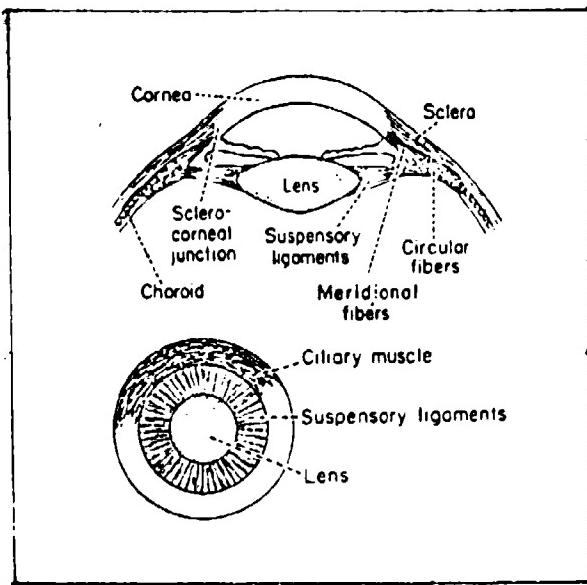


Figure 3. Mechanism of Accommodation (Ref. 8)

also be stimulated voluntarily. Accommodation allows the eye to adjust its focus for the viewing of both distant and near objects (Ref 8).

The accommodative response (i.e. how much the lens changes refractive power to try to focus on an object) is influenced by the viewing conditions. Generally, errors in accommodation occur under conditions of low luminance or low contrast. Accommodation also varies with the spatial frequency of sine-wave gratings. Similar to contrast sensitivity, the accommodative response is best for the middle frequencies (Ref 3).

## II. Apparatus

### Variable Contrast Device

Theory. A variable contrast device (VCD) uses the properties of polarizing filters to vary the contrast of slide stimuli from zero to 100 percent contrast (Ref 1). A large disk of polarized material is mounted on a rotatable wheel. As the disk is rotated, the direction of polarization changes. The target is projected through a small polarized filter. A constant luminance source is projected through a second small polarizer which is  $90^{\circ}$  out of phase with respect to the first polarizer. Rotating the large polarizer through 90 degrees varies the target contrast continuously.

Equipment. The VCD used is shown in Figure 4. It consisted of two projectors, two small polarizers, and a large polarizer on an electrically controlled mount. There was also a control box and a digital readout for the rotation device and an electronic slide selector.

Calibration. The VCD was calibrated using a photometer and a stimulus slide. The large polarizer was rotated to totally block the output of the constant luminance source. The luminance of a light area of the image was measured using the photometer. The large polaroid disk was then rotated to block the luminance from the stimulus projector. The luminance level of the constant luminance source was adjusted to match that of the stimulus source. The

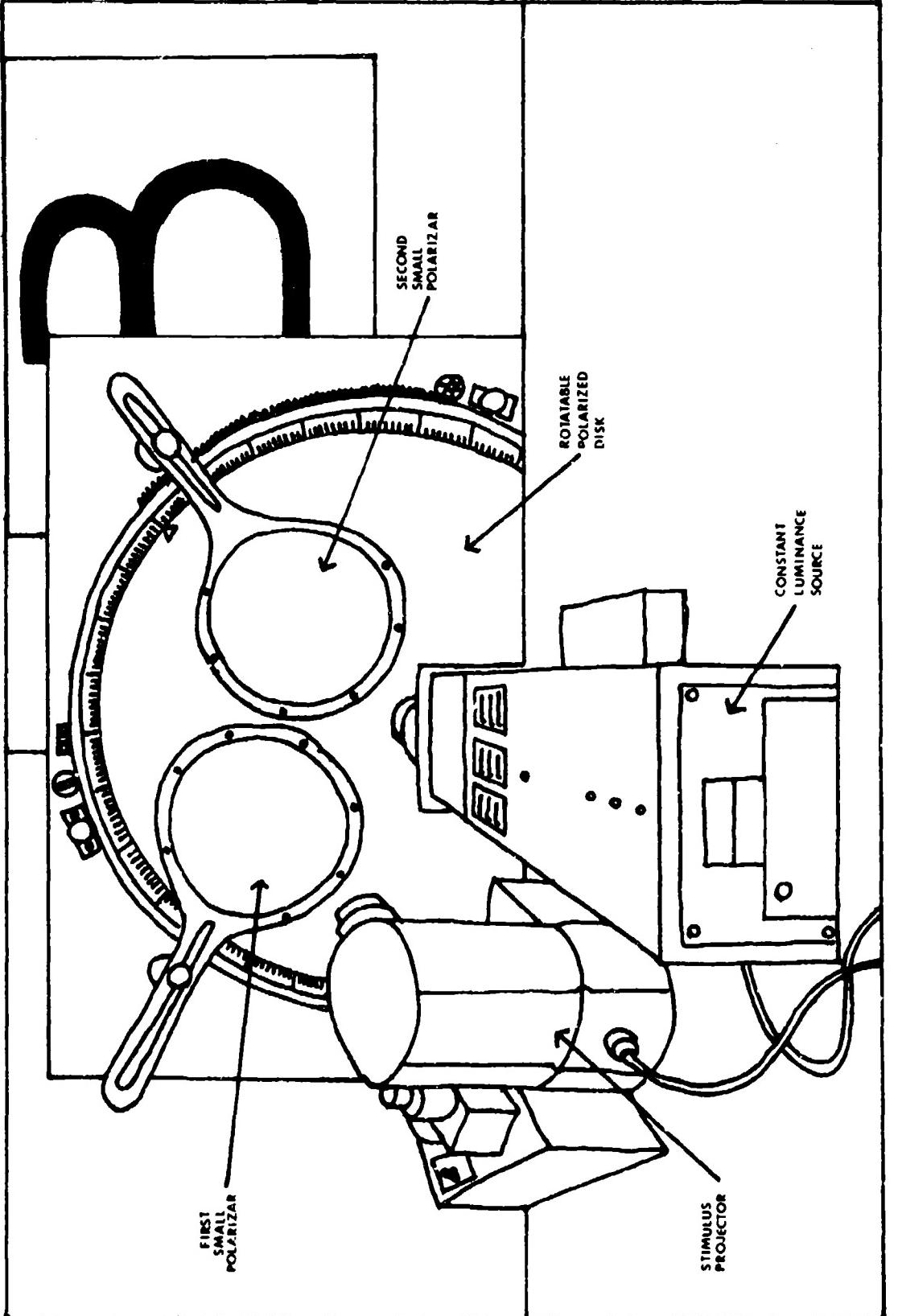


Figure 4. Variable Contrast Device

variation in the mean luminance was then checked by slowly rotating the large polaroid disk and noting changes in the luminance. The variation did not exceed two percent.

The basic contrast of the sine-wave gratings was determined by measuring the luminance of the peak and trough of each grating. The contrast was determined by Eq. 1.

After the preliminary calibration was complete and the luminance of both channels matched, a calibration curve was determined. The photometer was first focused on the dark area of the stimulus. The polaroid disk was rotated to block the constant luminance source. The polaroid disk was then rotated in five degree increments and the digital readout and the luminance of the dark area of the image were recorded. The contrast at each five degree increment was calculated. For sine-wave gratings this contrast value was normalized by dividing by the average of all the contrast readings. This normalized contrast was then multiplied by the peak contrast of the slide to determine the final contrast. The contrast values were plotted vs. the digital readout so that direct readings of contrast sensitivity could be made be using the digital readout and the calibration curve.

The luminance of both the stimulus and constant light source were checked and set equal before each test session. The peak luminance, 10 foot lamberts, was reduced to 6 foot lamberts by the beam splitter of the Badal optometer that is described below. The digital readout was also checked, with

the low end being set to one hundred and the high end noted. At the end of each session the luminance values and readout were checked for drift. For the most part the luminance remained steady for the duration of the session. The few times the luminance did drift the session was repeated.

#### Badal Laser Optometer

Theory. An optometer is an instrument used to measure the accommodative state of the eye. The optometer used for these experiments incorporated laser refraction and the Badal principle. The basic theory of a Badal laser optometer can be explained by using the simplified diagram shown in Figure 5.

In a laser optometer, light from a low power laser is reflected onto the surface of a slowly rotating drum, giving it a speckled appearance. This speckle pattern, when superimposed on the subject's visual field by a beam-splitter, appears to move either with or against the rotation of the drum. The direction of the movement of the speckles depends on the refractive state of the eye. If the subject is accommodated to distances nearer than the focal plane of the object, the speckles move in the same direction as the drum. If the accommodation is further than the focal plane of the object, the speckles will move in the opposite direction. By changing the position of the drum, a point can be found where there is no movement of the speckle pattern. At this point the subject's eye is conjugate to the optical distance of the plane of stationarity of the

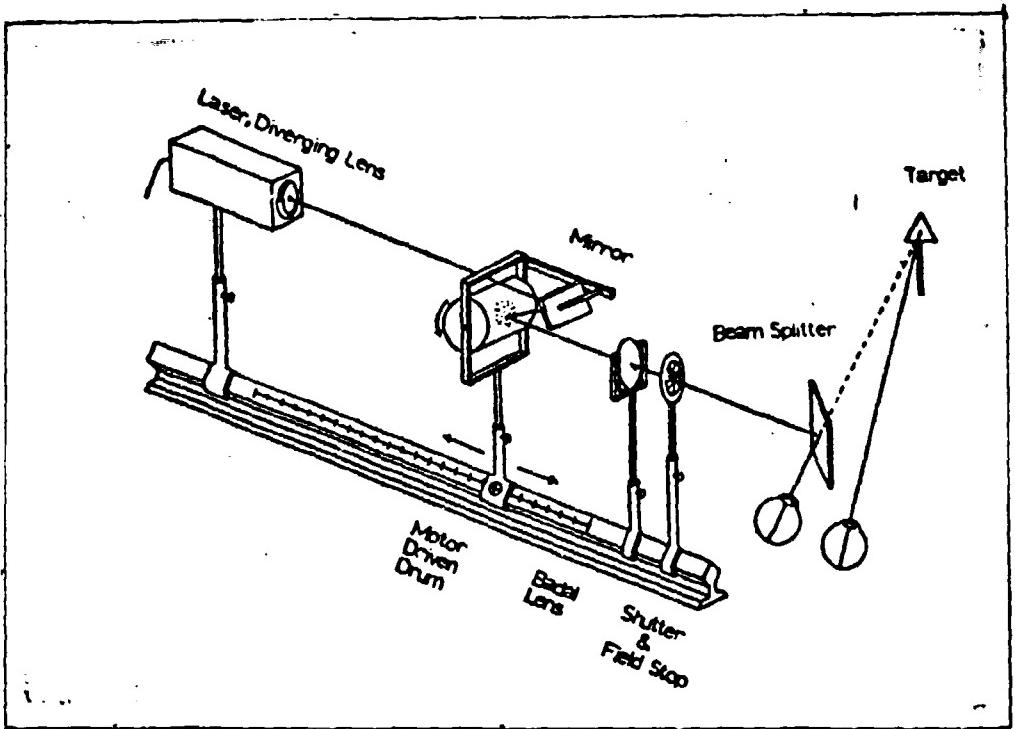


Figure 5. Simplified Badal Laser Optometer  
(Ref 9:238)

speckle pattern. (See Appendix A for an explanation of the plane of stationarity.) Using the distance of the drum from the lens and the Badal principle the subject's accommodation can be measured (Ref 9,10).

The Badal principle (Ref 11) used the fact that if the eye is at the focal point of a convex lens, the virtual image of an object placed between the lens and its anterior focal point will always subtend the same visual angle. At the same time, the accommodation needed to focus the image varies with the distance of the object from the lens. When the object is at the anterior focal point of the lens, the eye views the image at infinity. As the object approaches the lens, the image distance approaches the focal length of the lens. The Badal formula, relating the object and image

distances, is:

$$Q = F^2(d - 1) \quad (2)$$

where  $Q$  is the image distance, or accommodation, in diopters,  $F$  is the focal length of the lens in diopters, and  $d$  is the distance between the drum surface and the object in meters. As can be seen, when the object is at the focal point of the lens,  $d=1/F$ ,  $Q=0$ , and if the speckle pattern appears stationary at this point the subject is focused at infinity.

Equipment. A schematic of the optometer used in this experiment is shown in Figure 6. The laser used was a Spectra Physics Model 155 .5mW HeNe laser (L). The collimator (C) collimated the diverging laser light so the speckle pattern remained constant as the drum moved back and forth. Two relay mirrors (M<sub>1</sub>, M<sub>2</sub>) reflected the collimated beam through the electronic shutter (S) onto the mirror (M<sub>3</sub>) mounted on the drum (D). This mirror reflected the beam onto the surface of the rotating drum. The speckle pattern created by the laser reflecting off the rotating drum then passed through a +12 diopter lens (L<sub>1</sub>) and a beam-splitter (BS) which superimposed the speckle pattern on the subject's field of view.

The electronic shutter limited the exposure time of the speckle pattern to 0.5 seconds. This interval was found to be short enough to avoid any tendency to accommodate on the speckle pattern (Ref 9).

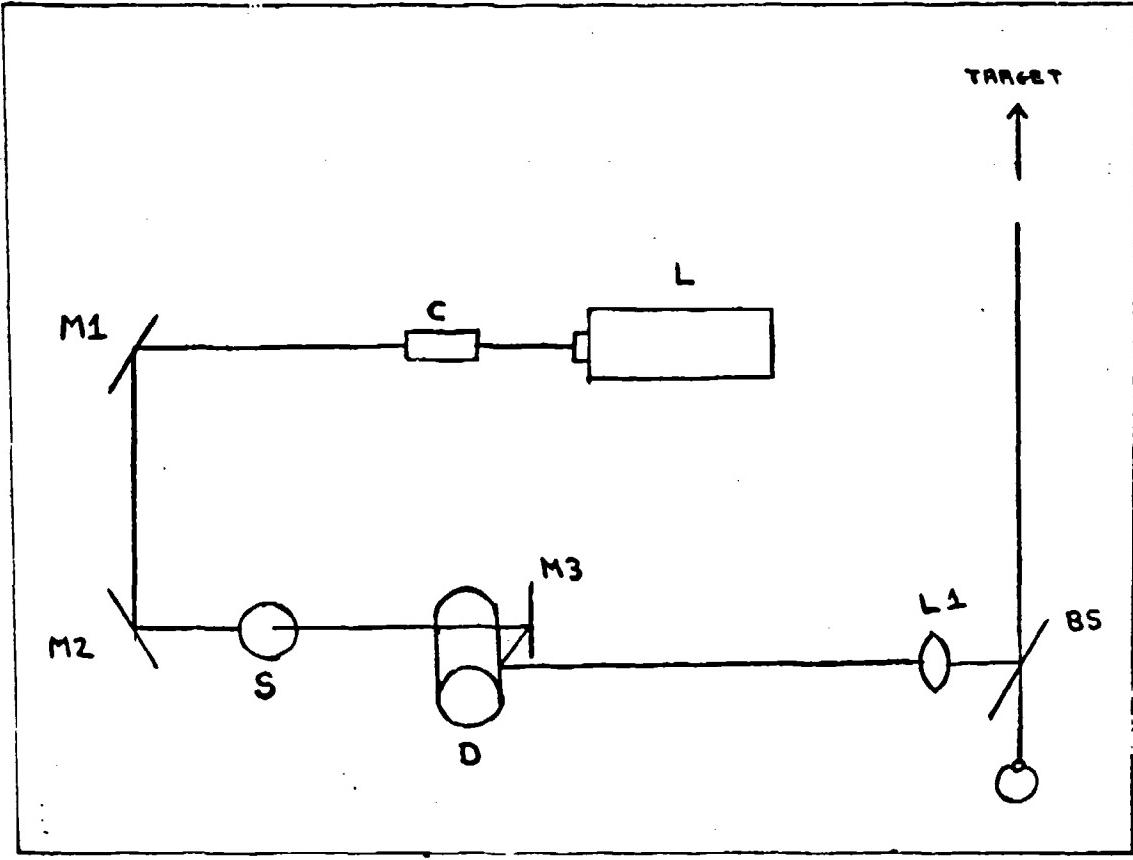


Figure 6. Schematic of Badal Laser Optometer Used

A chin rest provided the proper positioning of the subject with the left eye at the focal point of the +12 diopter lens (L). The drum was mounted on a motor driven slide which was attached to a digital readout for accurate measurements. The range of the optometer was from -7.0 to +11.9 diopters.

Calibration. After the initial set-up and alignment of the optometer the only calibration consisted of resetting the digital output of the motorized slide to start at the zero point before each accommodation measurement. This was accomplished by moving the drum to a specified starting position very close to the lens and resetting the output

display to zero.

The alignment was also checked each day to assure a constant speckle position on the drum. If the speckle pattern drifted adjustments were made to keep the pattern in the center of the subject's field of view.

### III. Experimental Method

#### Sine-Wave Gratings

The subject's contrast sensitivity to sine-wave gratings was determined using sine-waves of six different spatial frequencies: 0.61, 1.76, 4.6, 16.2, and 22.0 cycles per degree (cpd) of visual angle. The spatial frequency of the slide was determined by:

$$CPD = \frac{2 \times \sin(.5) \times dis}{Object\ Size} \quad (3)$$

where CPD is cycles per degree, dis is the viewing distance, and object size is the number of cycles in the grating per centimeter. The slides were viewed monocularly using the left eye at a distance of 4 meters. Seven different viewing conditions were tested; normal vision and viewing the target through lenses of +1, +2, +3, +4, +5, and +6 diopters.

To achieve consistancy between the contrast sensitivity and accommodation measurements all the testing was done with the subject looking through the beam-splitter of the optometer. For the contrast sensitivity measurements the shutter remained closed and the drum was set at a distance where it would not interfere with the contrast readings.

The subject was first shown the grating to be identified at high contrast. The contrast was then set to zero. The subject was directed to slowly increase the contrast until some of the bars of the grating were just

visible. Since a measurement of accommodation is only valid if the subject is actually accommodating on the target, the subject was further instructed to be sure the grating could be focused on and did not totally disappear after one or two seconds. After a threshold setting was made the contrast was lowered again and another setting was made by the subject. Five settings were made for each grating and an average was determined.

The contrast was then set at the average value so the subject's accommodation could be measured under the threshold conditions. Before starting the accommodation measurements the subject was instructed to be sure to focus on the sine-wave grating. The subject was further instructed to stay relaxed and not to strain or stare at the screen. If the grating faded the subject was told to blink, or to use both eyes to re-focus the grating before continuing with the accommodation measurement.

The accommodation measurement was made using a bracketing technique. The drum of the optometer was moved from one end of the scale to the other to try to elicit alternating up and down responses while zeroing in on the stationary region. Due to the sensitivity of the optometer, a single value for accommodation could not be obtained. Instead, the range of values over which the speckle pattern remained stationary was noted and an average value was used.

### Snellen Letters

The subject's contrast sensitivity for both detecting and identifying Snellen letters was determined. This was done using three different letters, E, B, and L, shown in Figure 7. Five spatial frequencies were tested: .43, 1.82, 3.4, 7.90, 11.85 cycles per degree. The spatial frequency of the letters was determined by Equation 3, with the letter width used as the object size.

Similar to the method used for the sine wave gratings, the slides were viewed monocularly using the left eye through the beam-splitter of the optometer from four meters. The subject was first shown all the slides to become familiar with the letters. The slides were then shown in a random order for testing purposes. The instructions were to raise the contrast until something could just be detected such as a dark spot or a blotch on the screen. The contrast setting for this detection was noted and the subject was instructed to continue to raise the contrast until the letter could be identified as an E, B, or L. After the correct identification was made the contrast was reset to zero and another slide was selected. Each slide was shown a total of three times and the results were averaged.

Accommodation settings were only made at identification contrast levels. This was done because at detection there was no distinct image to focus on so an accommodation measurement could not be made. It was also a strain on the subject to attempt to keep such a poorly defined target in

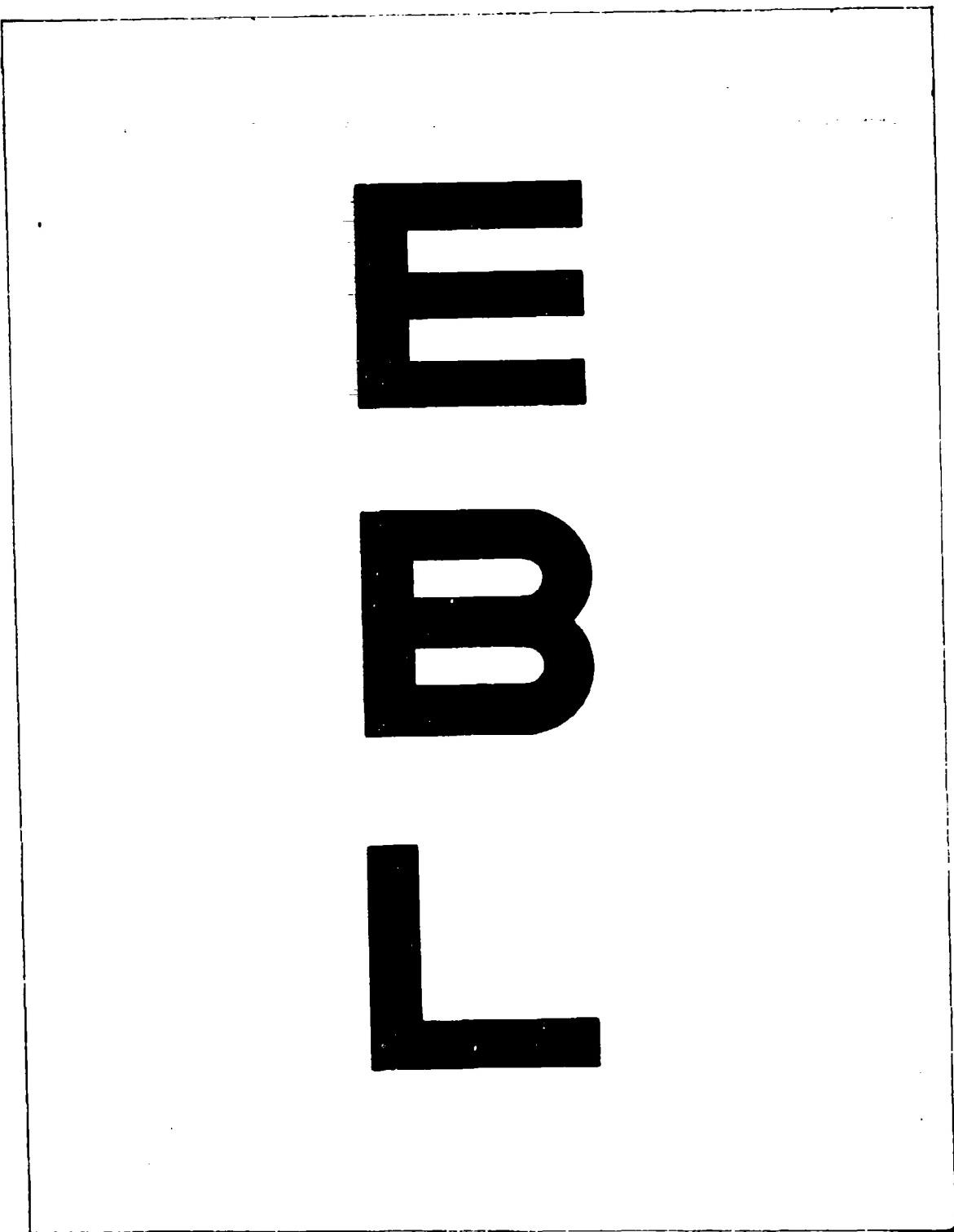


Figure 7. Snellen Letters

focus. The actual accommodation measurements for the letters were made in the same manner as those for the sine-wave gratings. Accommodation settings were only made for the letter E since there were no significant differences between the accommodation readings for the three letters and because accommodation measurements were both time consuming and tiring for the subject.

#### Airplanes

The subject's contrast sensitivity function for both the detection and identification of airplanes was determined. Frontal views of three airplanes were used as targets. The aircraft, shown in Figure 8, were a MIG-25, an F-15, and an RA-5C. The spatial frequency of the airplanes was determined by the total wingspan. The wing-tip to wing-tip width was used as the object width in Eq. 3. Four spatial frequencies were tested: .65, 1.25, 2.85, and 3.95 cycles per degree.

The CSF for the detection and identification of the airplanes was determined similar to the CSF for the Snellen letters. The accommodation measurements were also done similarly, with accommodation only measured for the F-15.

#### Low Luminance Conditions

Subject JC was further tested to determine the effects of low luminance. Contrast measurements for sine-wave gratings, Snellen letters E and B, and MIG-25 and F-15 airplanes were determined under several low luminance

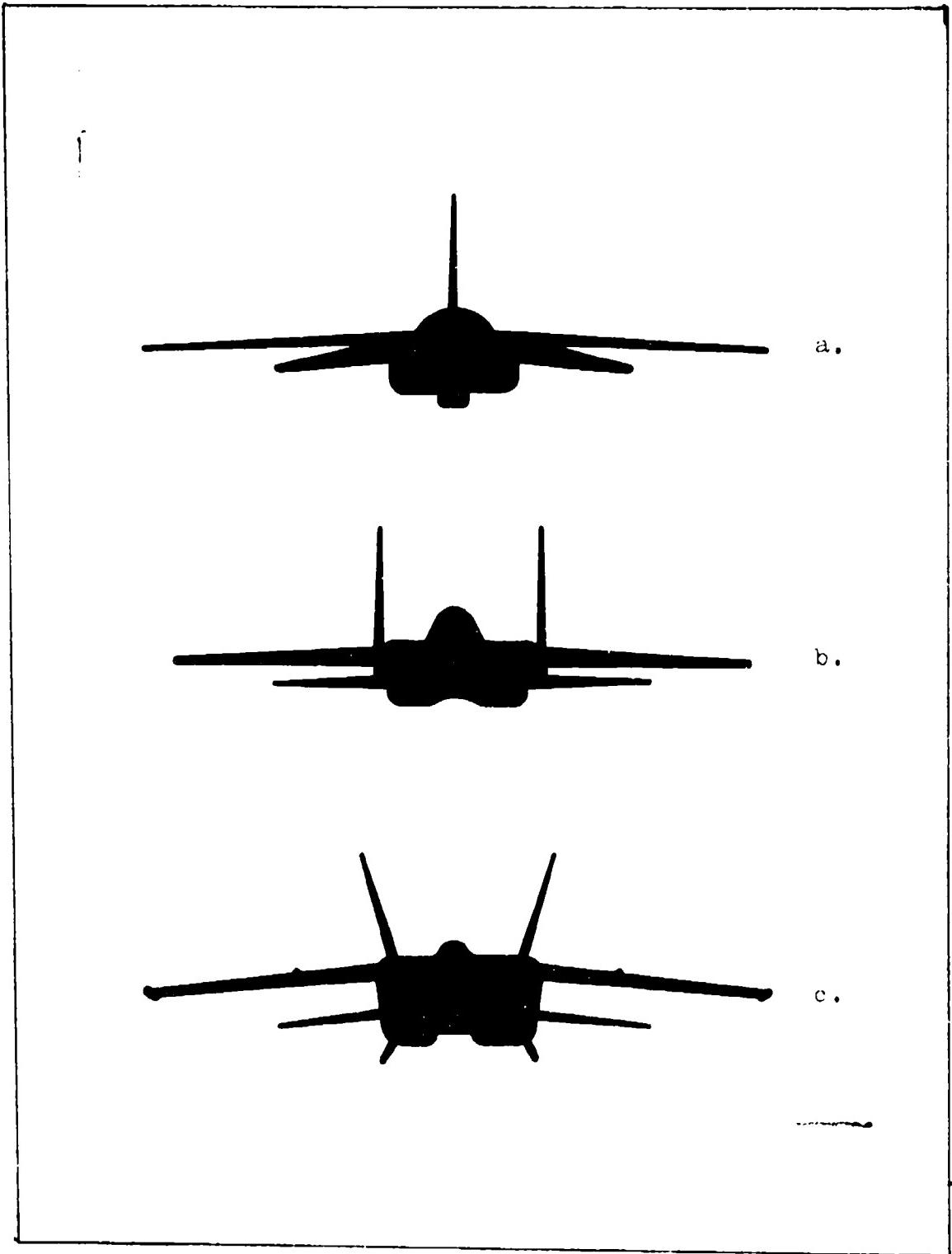


Figure 8. Aircraft: a) RA-5C b) F-15 c) MIG-25

conditions.

The low luminance levels were created by viewing the slides through neutral density filters. A neutral density filter reduces the luminance by powers of ten depending on the strength of the filter. For example, a neutral density 1 (ND1) filter reduces luminance by a factor of 10, ND2 by 100, and ND3 by 1000. The tests were run with ND1, ND2, and ND3 filters with refractive errors of 0, +2 and +4 diopters. The tests were conducted as before, except the subject dark adapted for fifteen minutes before starting. The reduction in luminance made it difficult to see the red speckle pattern of optometer so no accommodation measurements were made for these conditions.

#### IV. Results

Two subjects were tested for contrast sensitivity and accommodation for sine-wave gratings, Snellen letters E, B, and L, and MIG-25, F-15, and RA-5C aircraft. Plots of the results are shown in Appendix B. Subject JC was a myope corrected to 20/20. Subject JH was emmetropic with Snellen acuity of 20/15. Subject JC, with no induced refractive error, had difficulties at the highest spatial frequency and could not consistently detect the 22 cycles per degree grating. JH had no trouble with the highest frequency as would be expected from his Snellen acuity of 20/15.

In general, the greater the refractive error, the greater the degradation in contrast sensitivity. This was true for sine-wave gratings, letters, and aircraft.

##### Sine-Wave Gratings

**Contrast Sensitivity.** The contrast sensitivity functions for subjects JC and JH for 0-6 diopter refractive error as determined using sine-wave gratings, are shown in Figures 9 and 10. For subject JC the percent standard deviation of the individual settings from the averaged value remained below 10 per cent, with 92 per cent of the readings having standard deviations below 5 per cent. Subject JH had 81 per cent readings with standard deviations below 5 per cent with 16 per cent below 10 per cent standard deviation.

Subject JC showed a drop in the high frequencies at +1 diopter, and both JC and JH had a drop in the middle

## CONTRAST SENSITIVITY FOR SUBJECT JC

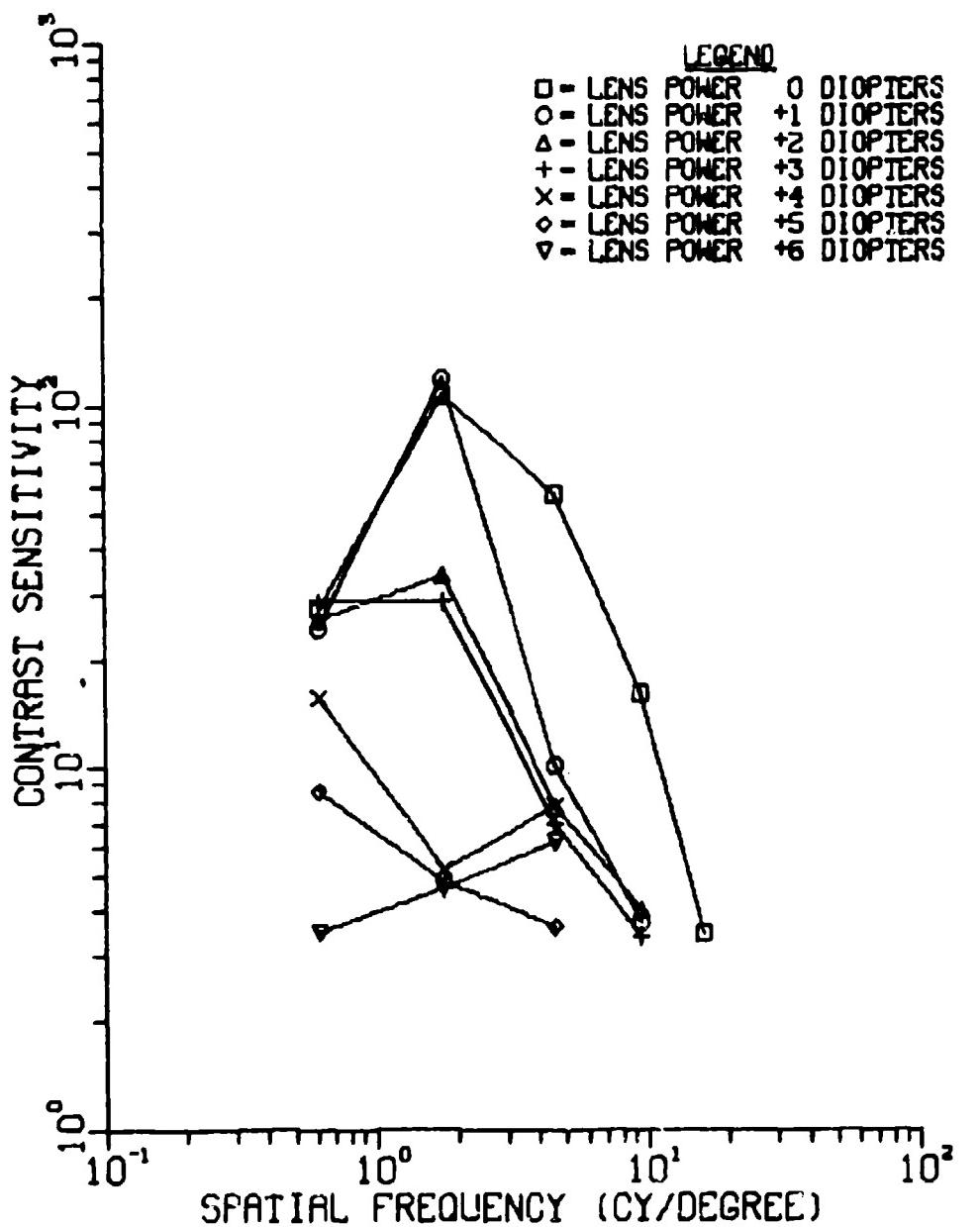


Figure 9. CSF for JC for Sine-Wave Grating Stimuli

## CONTRAST SENSITIVITY FOR SUBJECT JH

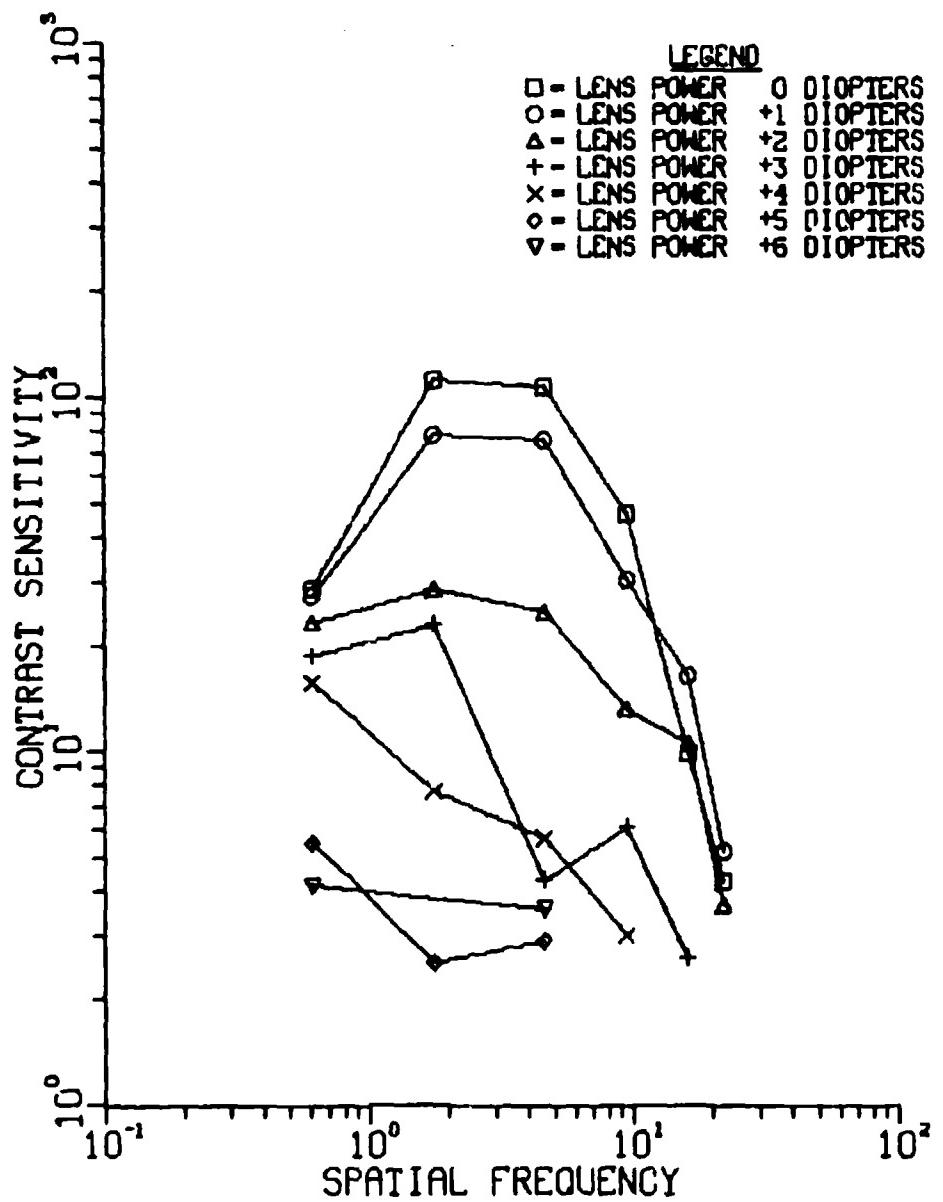


Figure 10. CSF for JH for Sine-Wave Stimuli

frequencies starting at +2 diopter. At +6 diopter subject JH could not even see the 1.76 cycles per degree grating.

Accommodation. The mean accommodation curves for JC and JH are somewhat different. As seen in Figure 11, subject JC showed a reasonably constant accommodation of approximately +3 diopter for 0 and +1 diopter error. For greater values of refractive error the accommodation began to jump from as low as 1.8 diopter to as high as 2.8 diopter. The range from the minimum accommodation to the maximum accommodation measured for a single stimulus was usually 1 diopter. A measurement of accommodation to within .5 diopter is usually considered good (Ref 11) . The other .5 diopter could result from actual focus changes during the accommodation measurement, or from equipment induced errors due to the large range of the optometer.

The accommodation response of subject JH, as seen in Figure 12, was also centered around +3 diopter. There was more variation in the individual curves though, especially for low values of induced refractive error. These variations could be due to actual focusing changes due to the low contrast and the inherent difficulty involved in trying to get a sine-wave grating in focus. The difference between the minimum and maximum values of accommodation for JH never exceeded .75 diopter.

#### Snellen Letters

Contrast Sensitivity. Sensitivity functions for JH and

# MEAN ACCOMMODATION FOR SUBJECT JC FOR SINE-WAVE GRATING

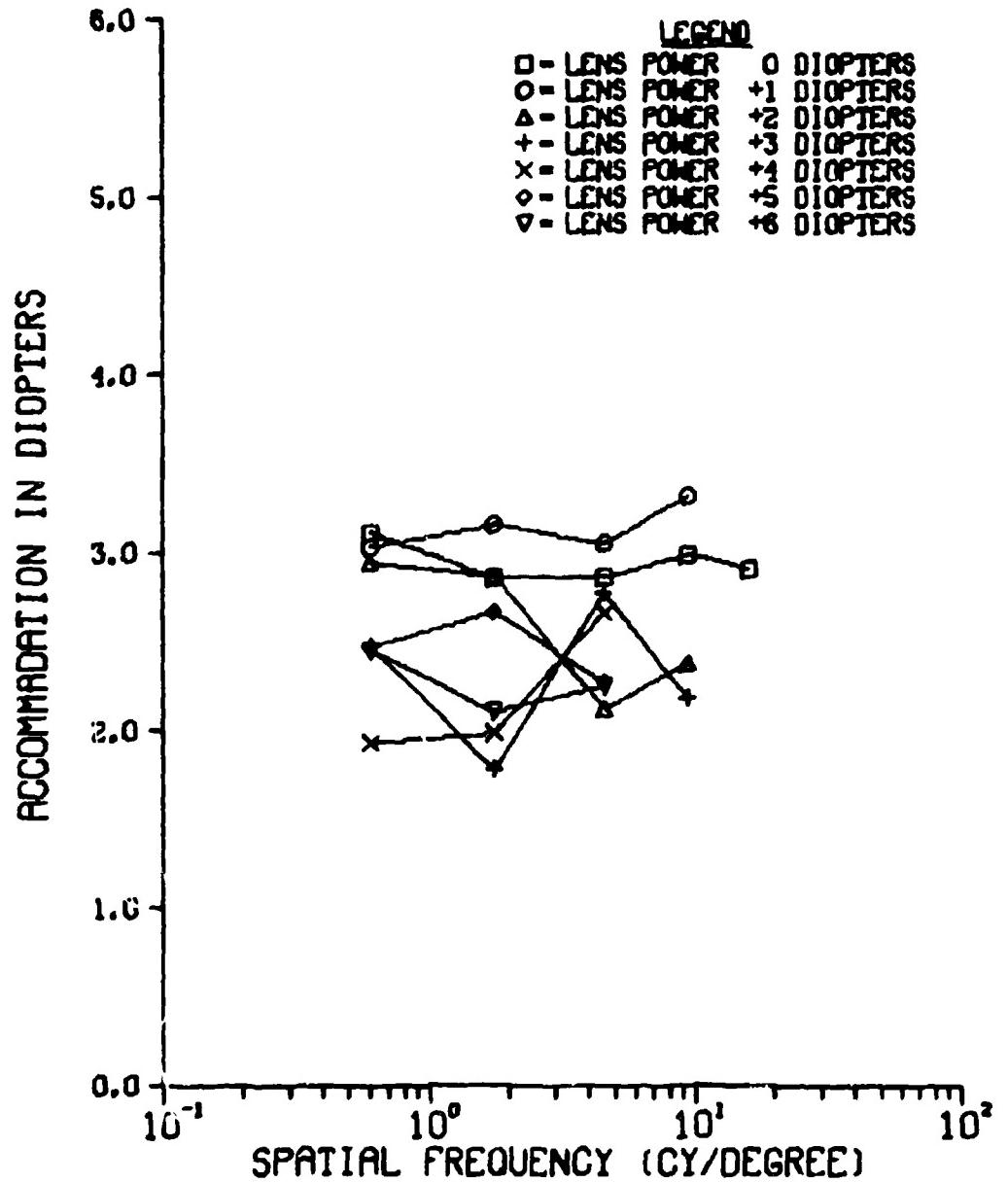


Figure 11. Mean Accommodation for JC for Sine-Wave Grating Stimuli

# MEAN ACCOMMODATION FOR SUBJECT JH FOR SINE-WAVE GRAINGS

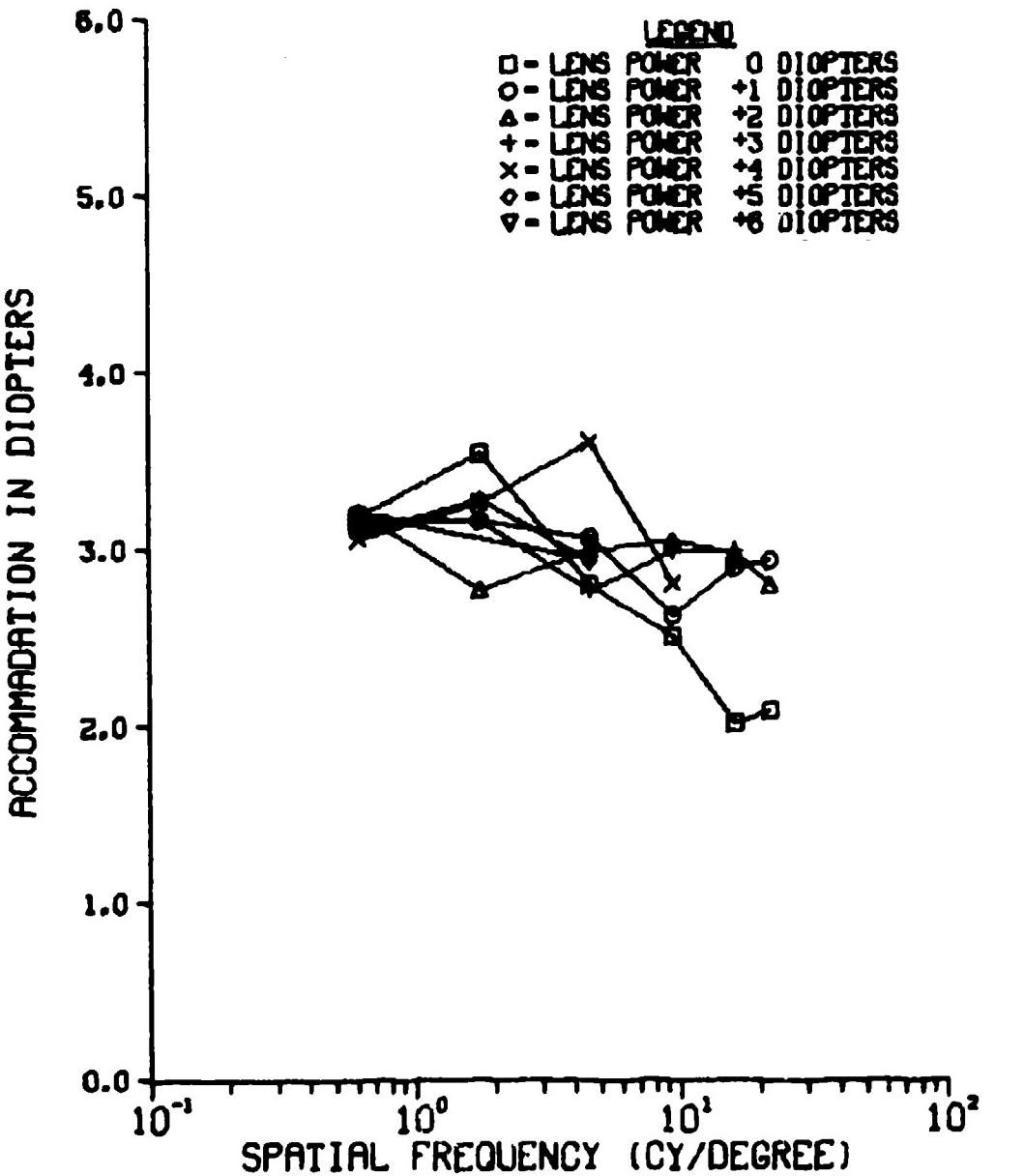


Figure 12. Mean Accommodation for JH for Sine-Wave Grating Stimuli

JC determined from the detection and identification of the Snellen letters E, B, and L are similar in form to the CSFs derived from the sine-wave gratings. From JH's CSF for sine-wave gratings it was seen that the response for +1 diopter error was close to the response for no refractive error. This relationship is also seen in the CSFs for the Snellen letters. Although the relationship was not as clear for JC, the CSFs for the letters do follow the same general pattern as those from the sine-wave gratings, especially at low values of refractive error. These results are reflected in the detection and identification CSFs shown in Figures 13-24.

Part of the discrepancies, especially at high values of refractive error, could be due to the basic differences between sine-wave gratings and letters. Sine-wave gratings were a repetitive pattern, filling the entire screen, while the Snellen letter only occupied a portion of the screen. It was possible, especially for the high spatial frequencies (small letters), to detect the letter late because the eye was scanning another part of the screen. This effect was minimized by raising the contrast slowly, but it still occurred at times. Adding to this problem was the fact that the letters appeared in slightly different positions on the screen. Since the slides were shown randomly it was necessary to scan the possible image area to find the letter.

Ginsburg found that for the detection of Snellen

DETECTION OF SNELLEN LETTER L  
FOR SUBJECT JC

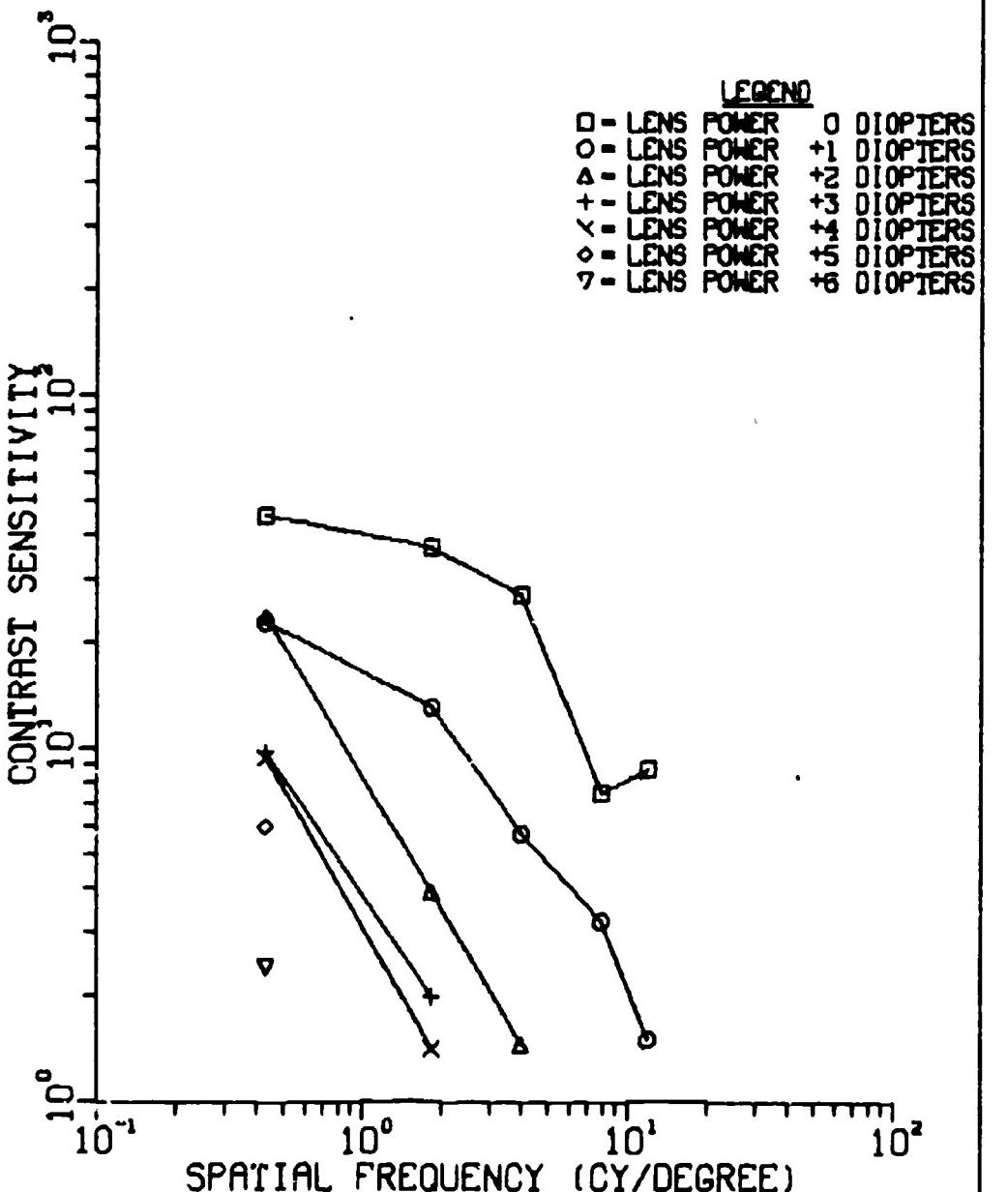


Figure 13. Detection of Snellen Letter L for JC

DETECTION OF SNELLEN LETTER B  
FOR SUBJECT JC

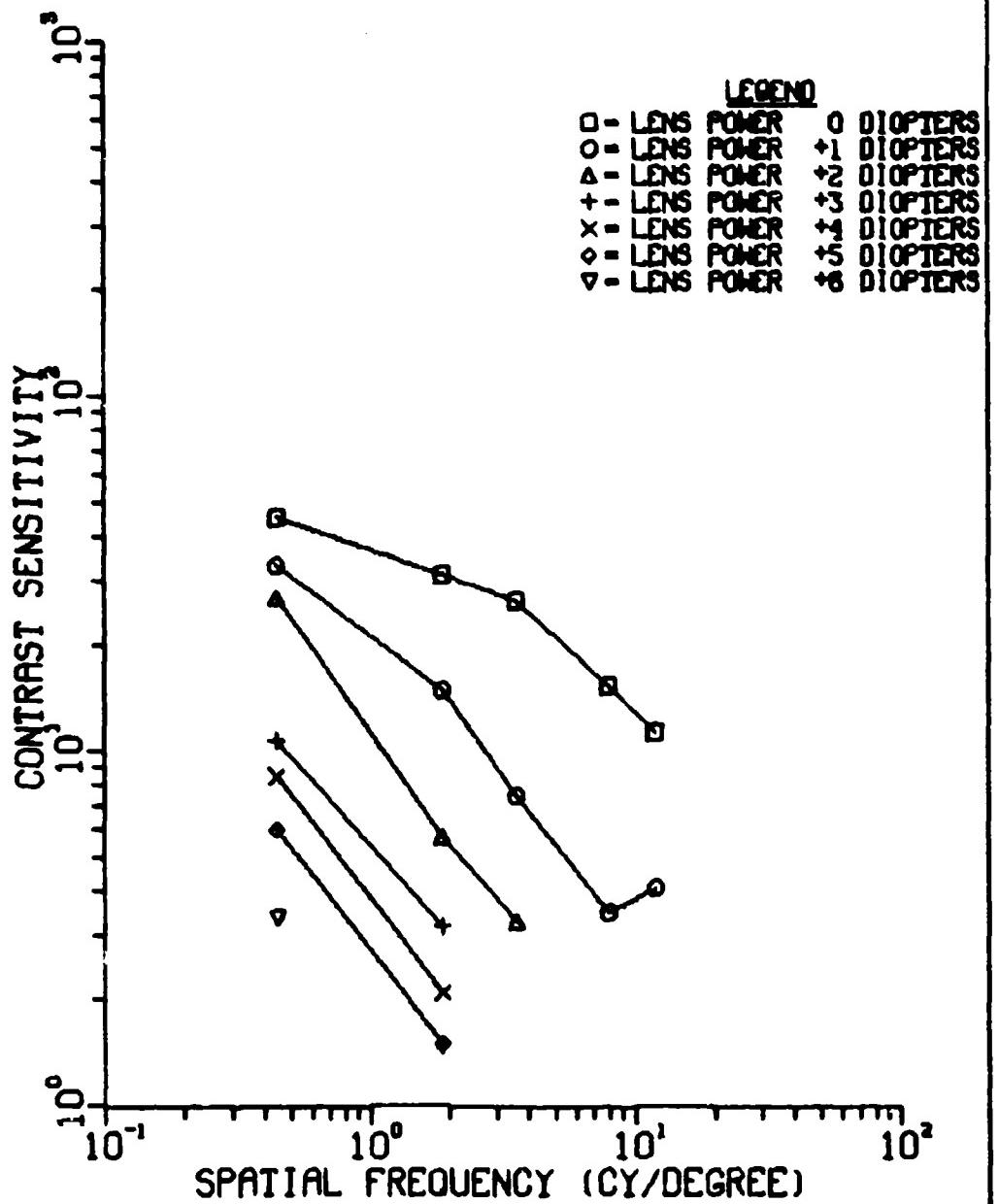


Figure 14. Detection of Snellen Letter B for JC

## DETECTION OF SNELLEN LETTER E

FOR SUBJECT JC

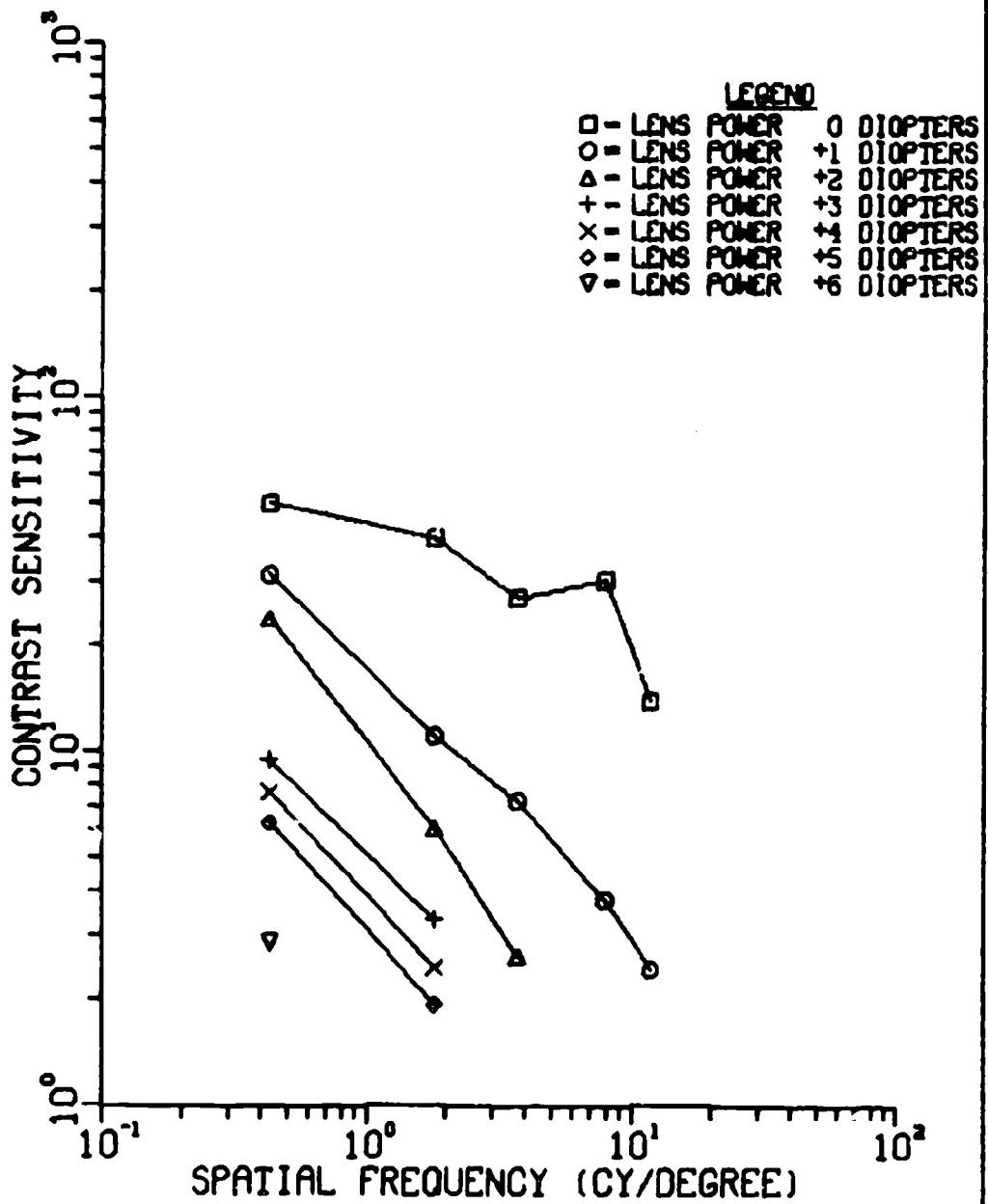


Figure 15. Detection of Snellen Letter E for JC

## IDENTIFICATION OF SNELLEN LETTER L

FOR SUBJECT JC

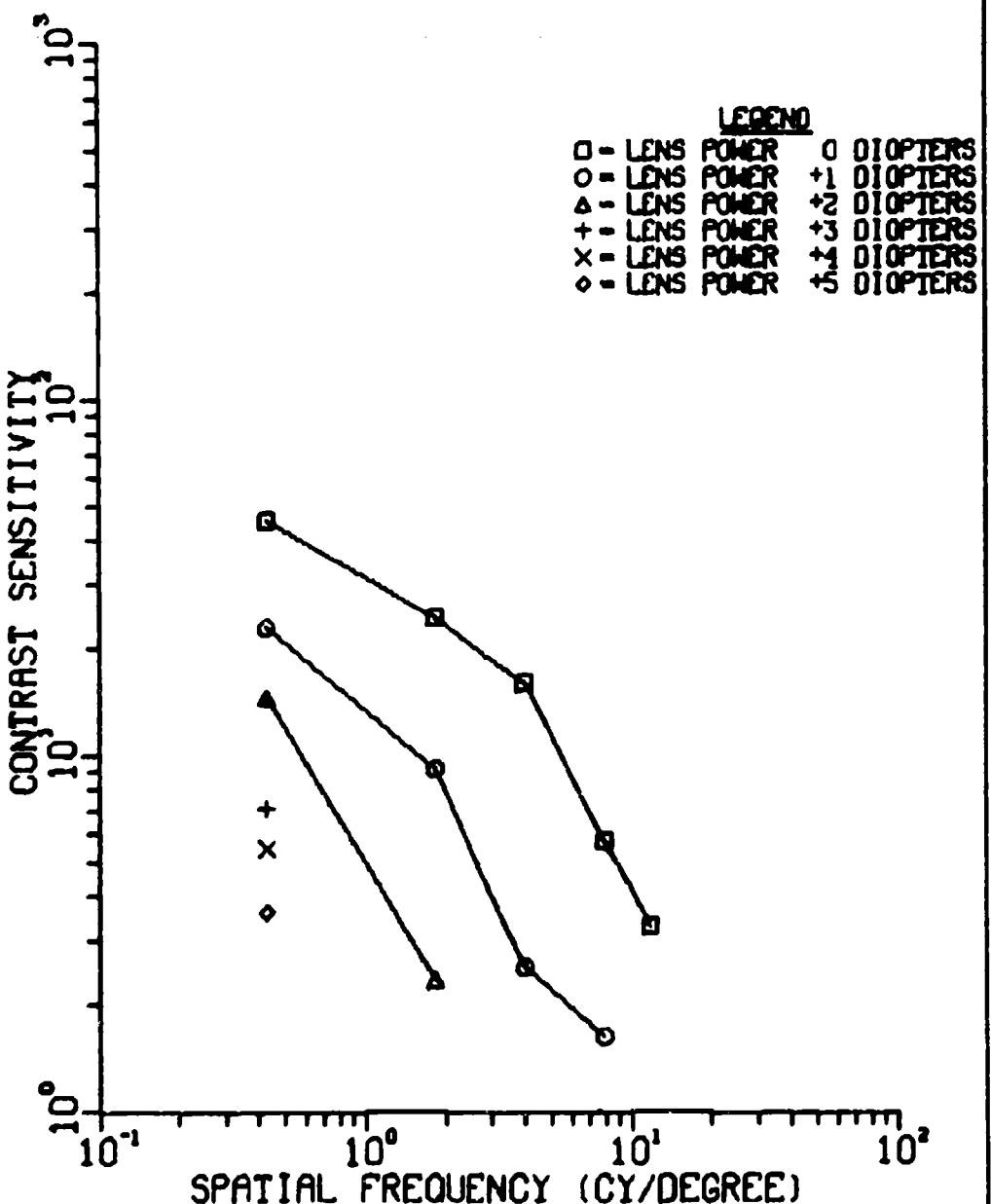


Figure 16. Identification of Snellen Letter L for JC

# IDENTIFICATION OF SNELLEN LETTER B FOR SUBJECT JC

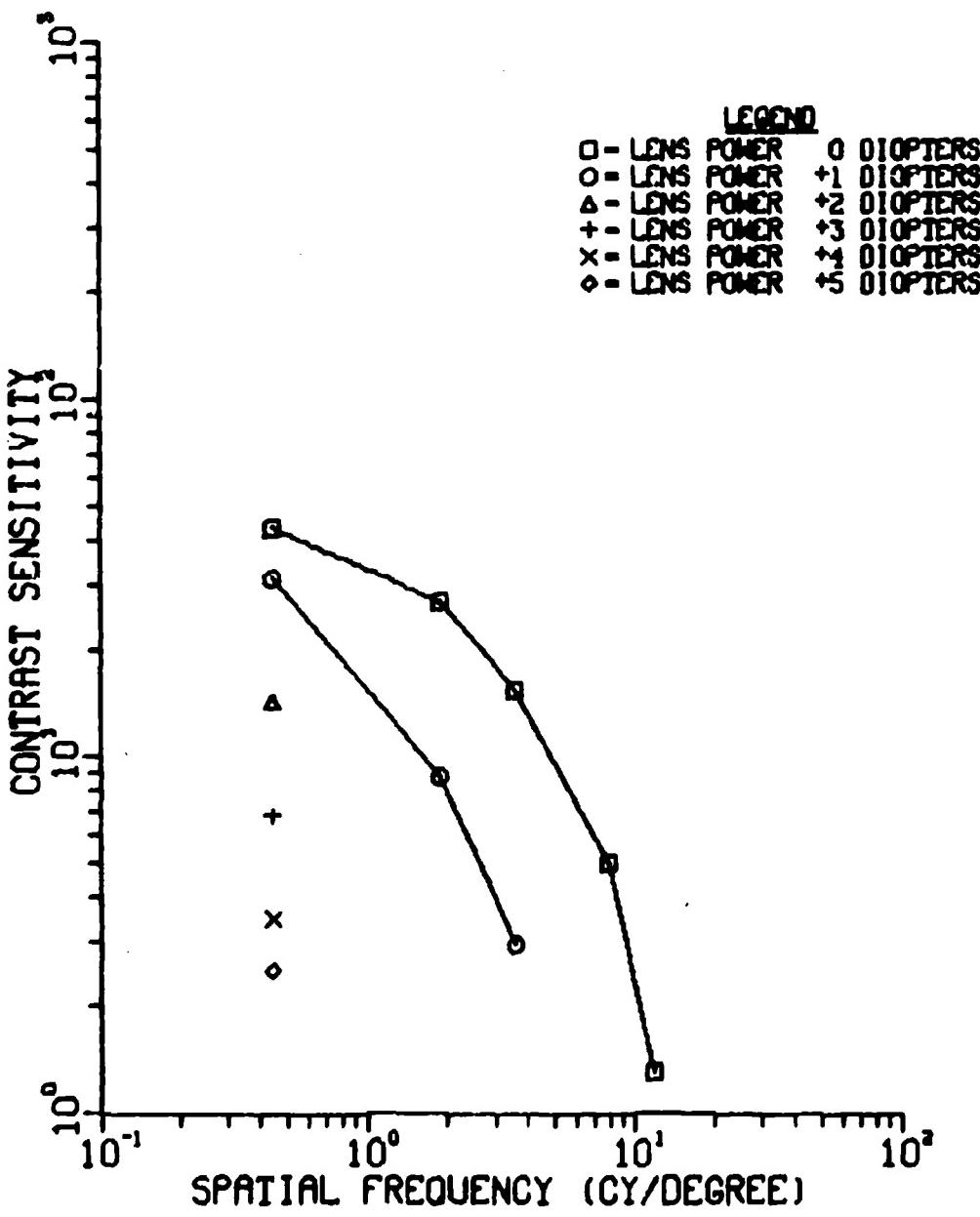


Figure 17. Identification of Snellen Letter B for JC

## IDENTIFICATION OF SNELLEN LETTER E

FOR SUBJECT JC

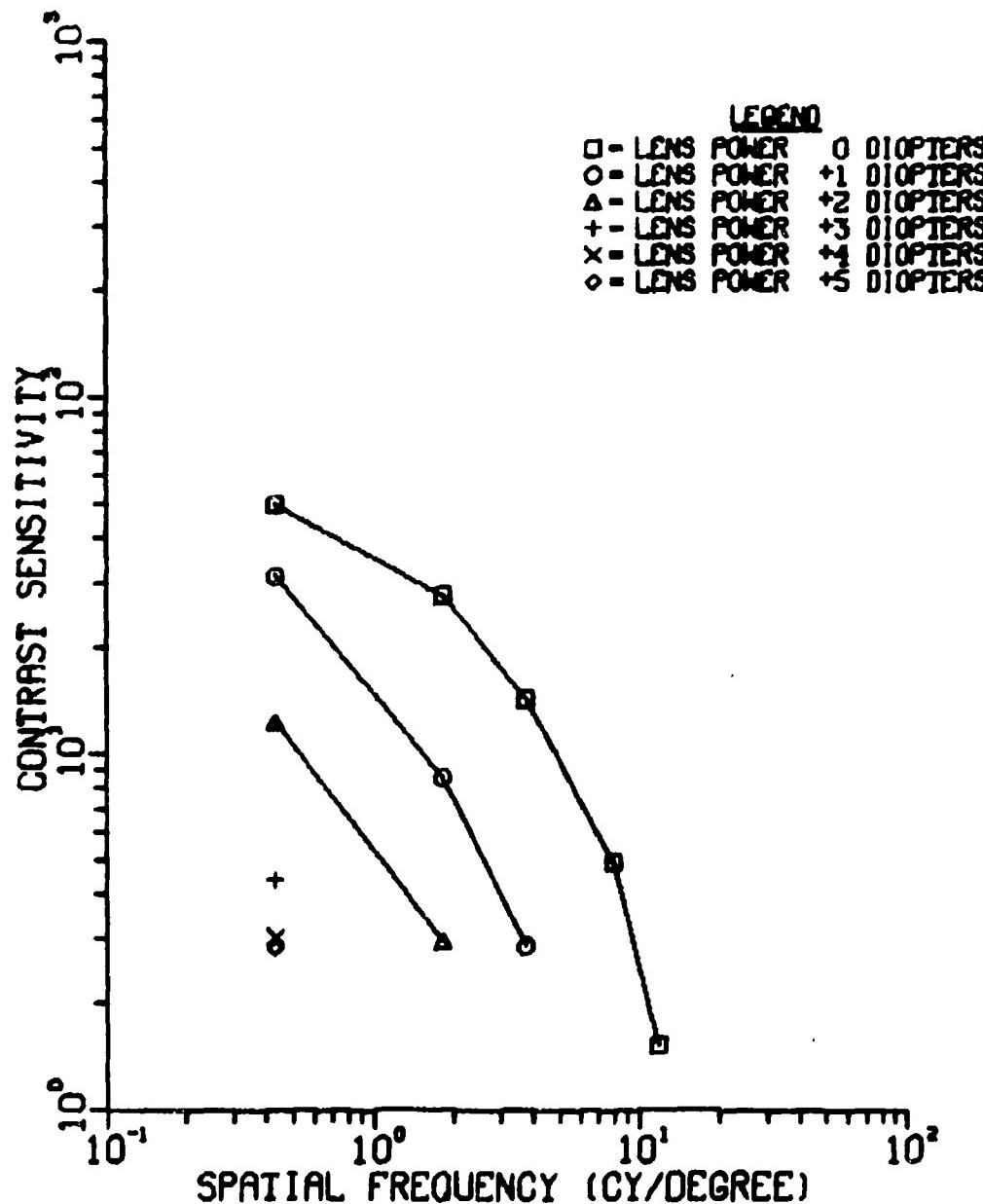


Figure 18. Identification of Snellen Letter E for JC

DETECTION OF SNELLEN LETTER L  
FOR SUBJECT JH

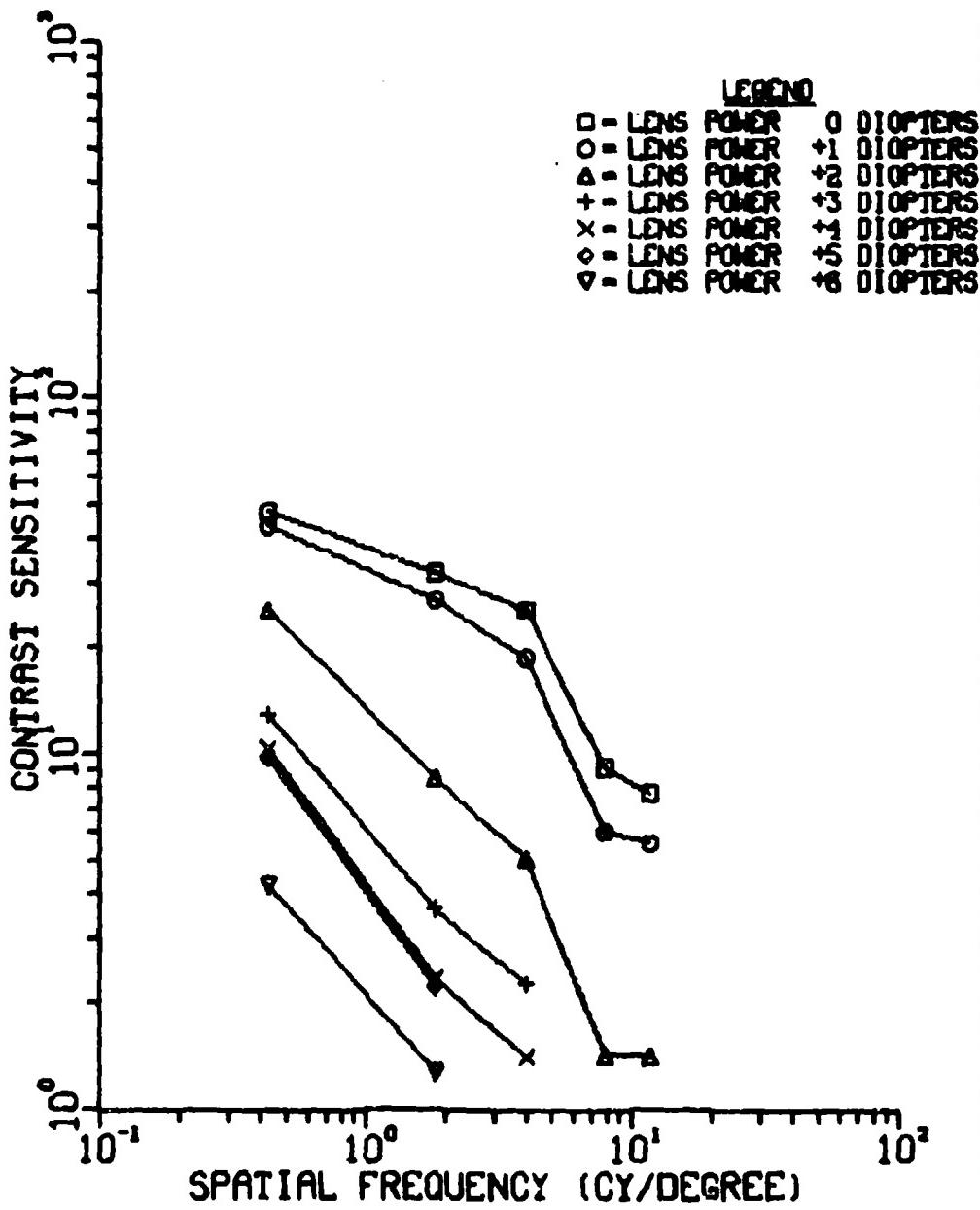


Figure 19. Detection of Snellen Letter L for JH

DETECTION OF SNELLEN LETTER B  
FOR SUBJECT JH

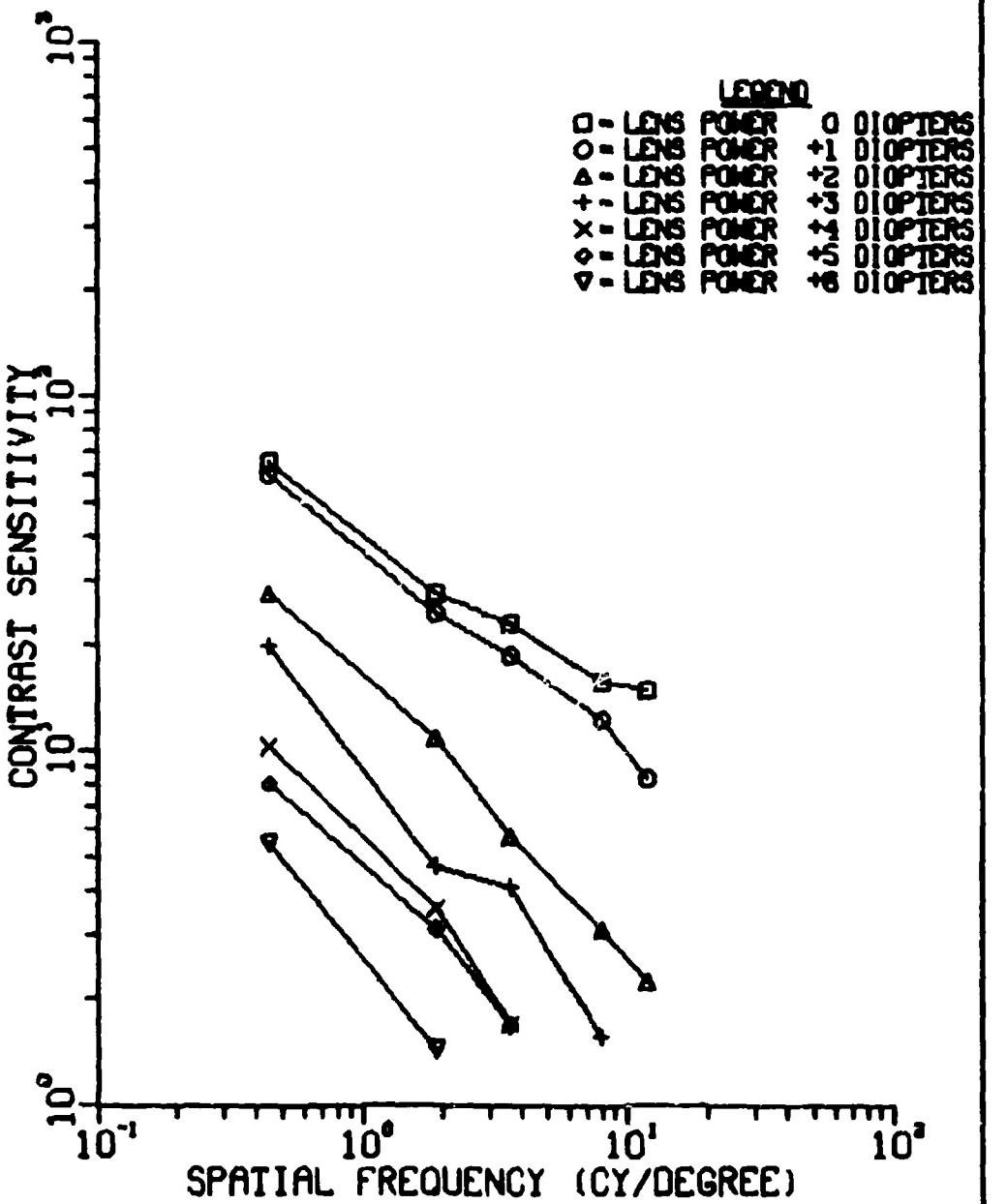


Figure 20. Detection of Snellen Letter B for JH

DETECTION OF SNELLEN LETTER E  
FOR SUBJECT JH

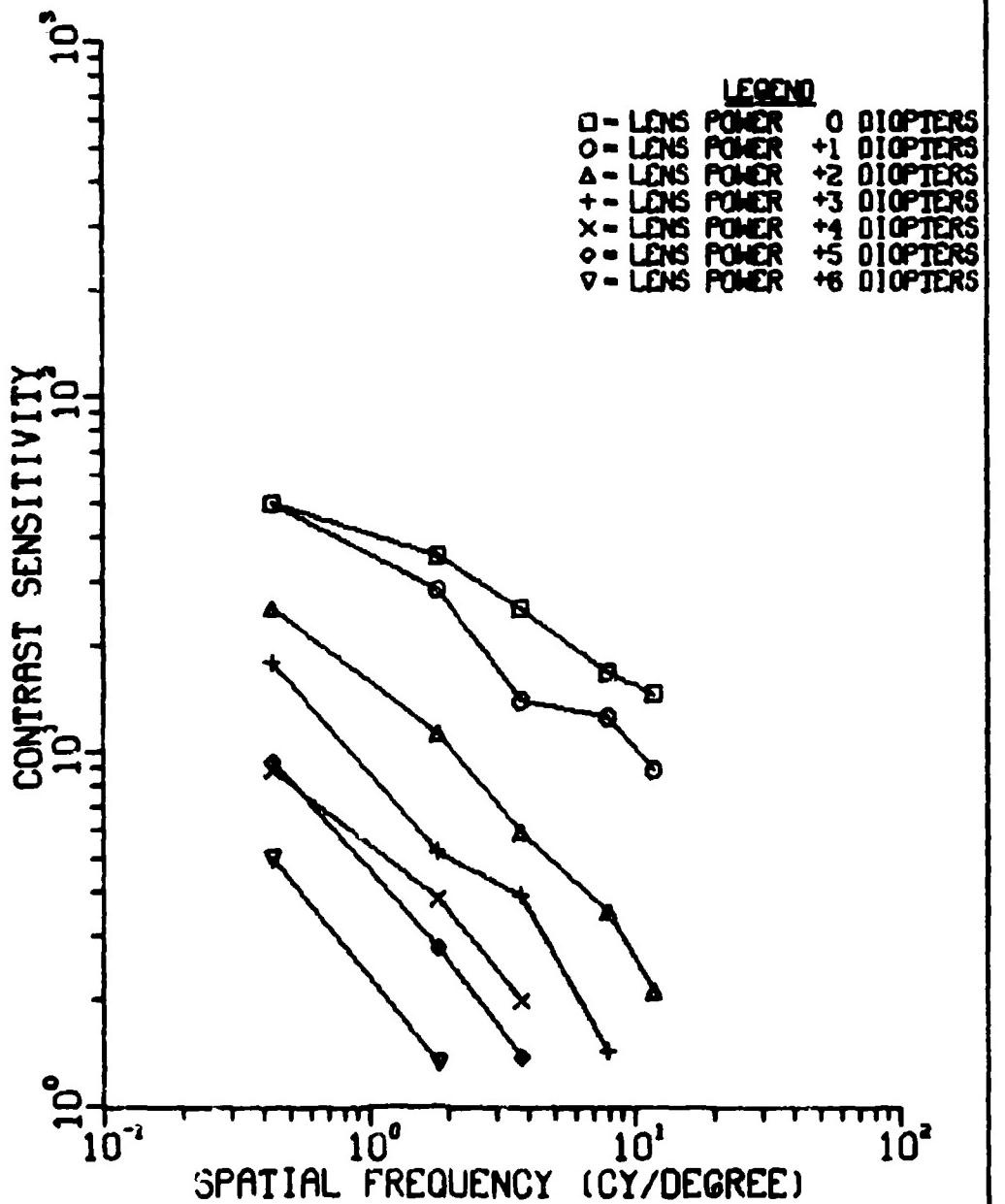


Figure 21. Detection of Snellen Letter E for JH

IDENTIFICATION OF SNELLEN LETTER L  
FOR SUBJECT JH

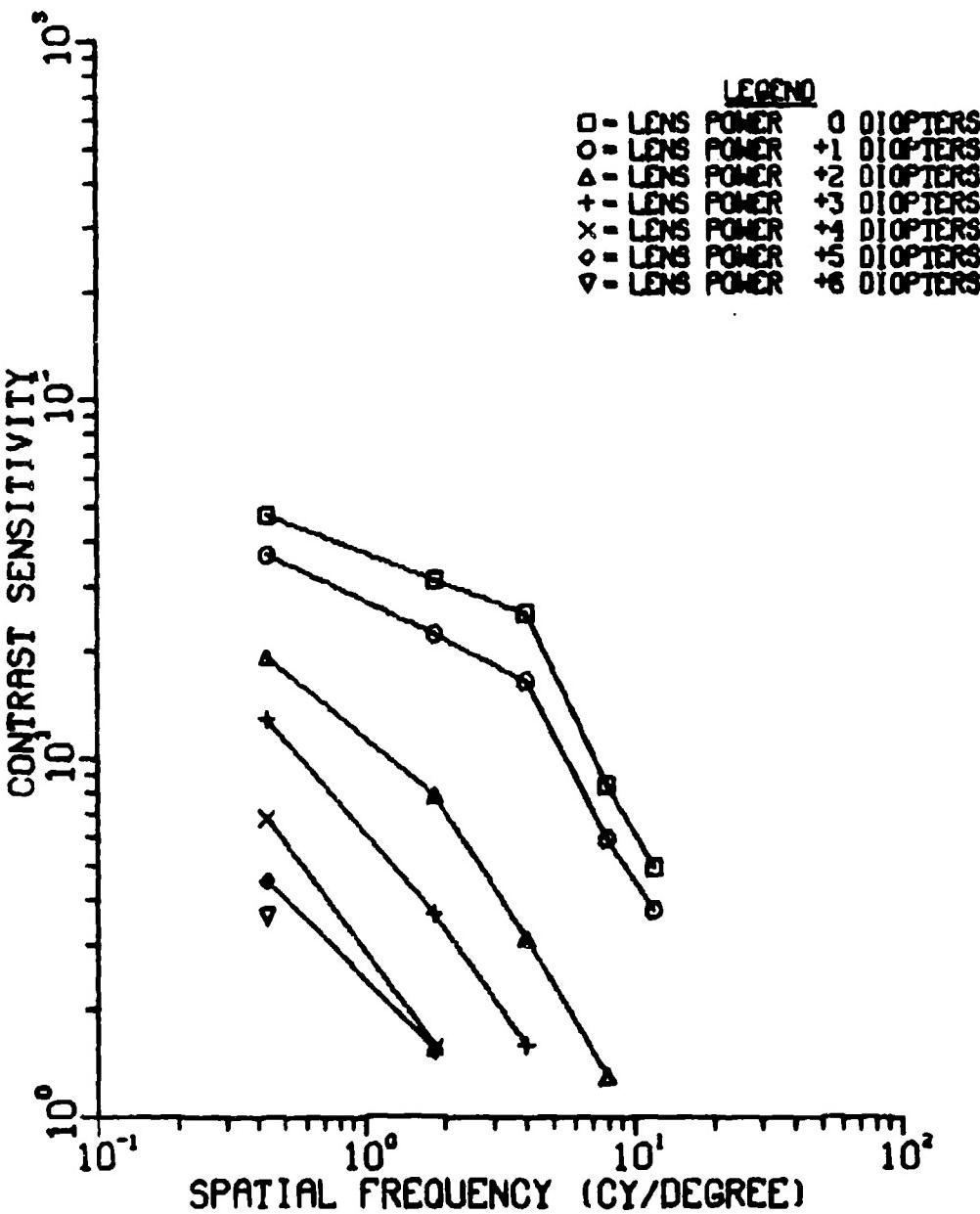


Figure 22. Identification of Snellen Letter L for JH

# IDENTIFICATION OF SNELLEN LETTER B FOR SUBJECT JH

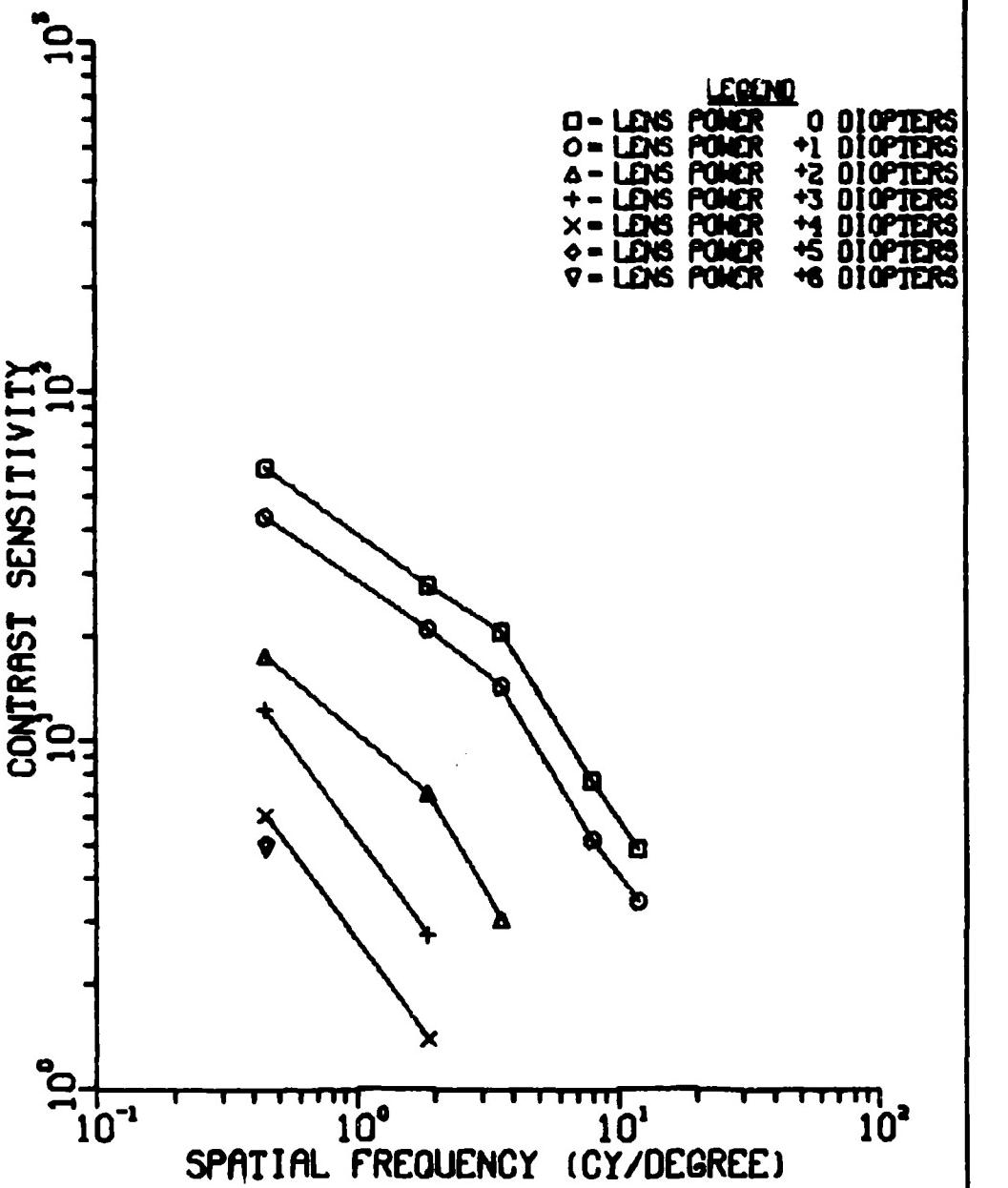


Figure 23. Identification of Snellen Letter B for JH

# IDENTIFICATION OF SNELLEN LETTER E

## FOR SUBJECT JH

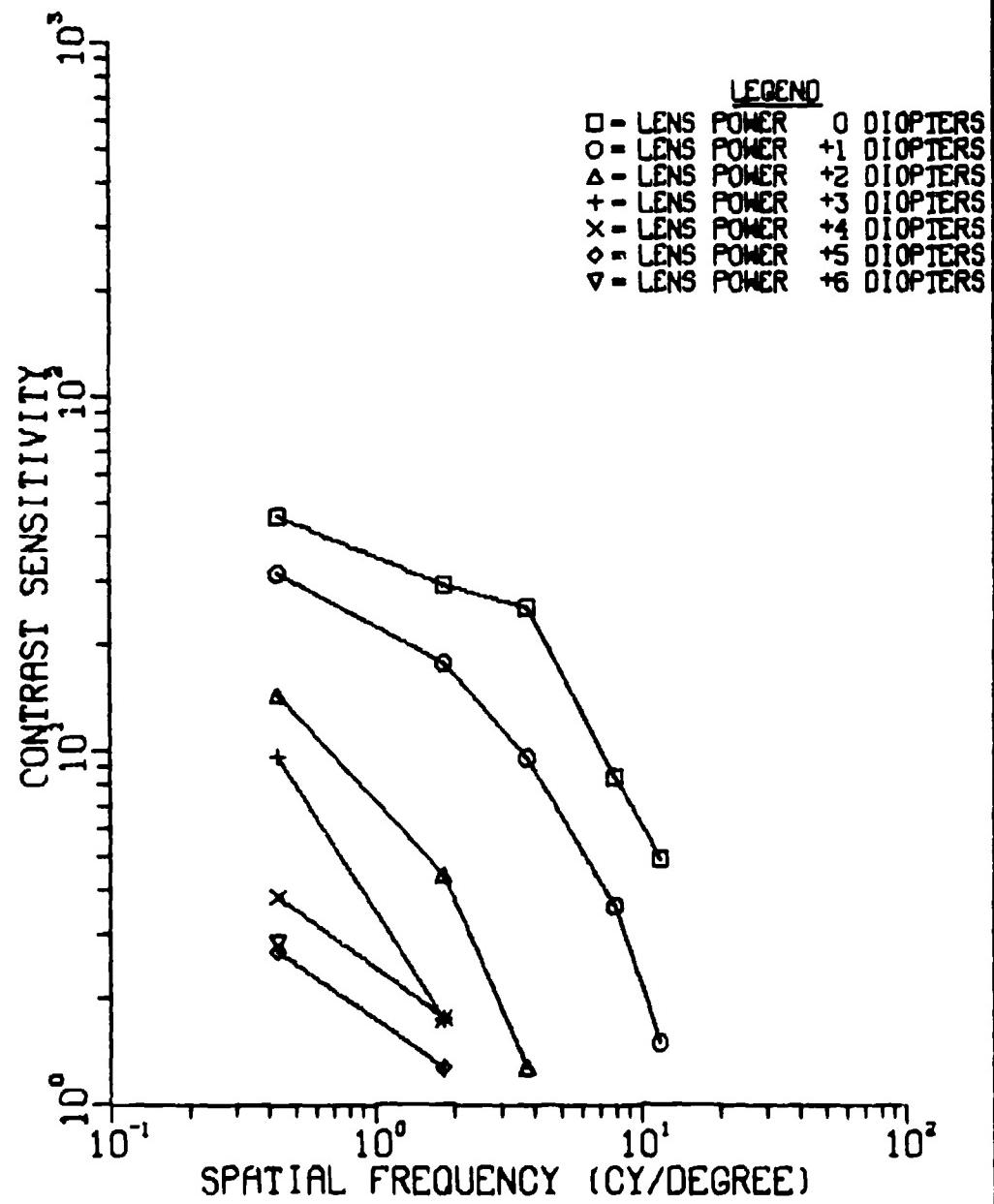


Figure 24. Identification of Snellen Letter E for JH

letters the response for a given spatial frequency relates best to the contrast sensitiviy from a sine-wave grating at half the frequency of the letter. For identification, the spatial frequency of a sine-wave grating at double the spatial frequency of the letter gave the best relationship (Ref 1). This relationship can be seen in the bandwidth calculations discussed below.

For both subjects, the L was harder to detect, but easier to identify under all conditions. These results could be predicted from Ginsburg's work with filtered images (Ref 1). This showed that an L could be recognized with only 1.5 cycles per letter width, while an E required 2.5 cycles per letter width.

Another area studied by Ginsburg (Ref 1) was the bandwidth required to go from detection to identification. This bandwidth was found by plotting contrast sensitivity on a logarithmic axis vs. spatial frequency on a linear axis. The regression lines extrapolated to the axis could then be used to find bandwidth as shown in Figure 25. Ginsburg found this bandwidth to be 2.4 cycles per letter width (cpl). For JC the bandwidth for all three letters ranged from 1.88 to 3.59 cpl with an average of 2.25 cpl. The letter L needed a smaller bandwidth (1.56 cpl). Also, the higher the values of refractive error needed a larger bandwdth, 2.29 cpl at 0 diopter and 2.62 cpl at +1 diopter. Subject JH showed the same type of result. The average bandwidth was 2.0 cpl, with the spread going from 1.09 cpl to 3.68 cpl. Again, the

DETECTION AND IDENTIFICATION OF SNELLEN  
LETTER B FOR SUBJECT JC (0 DIOPTERS)

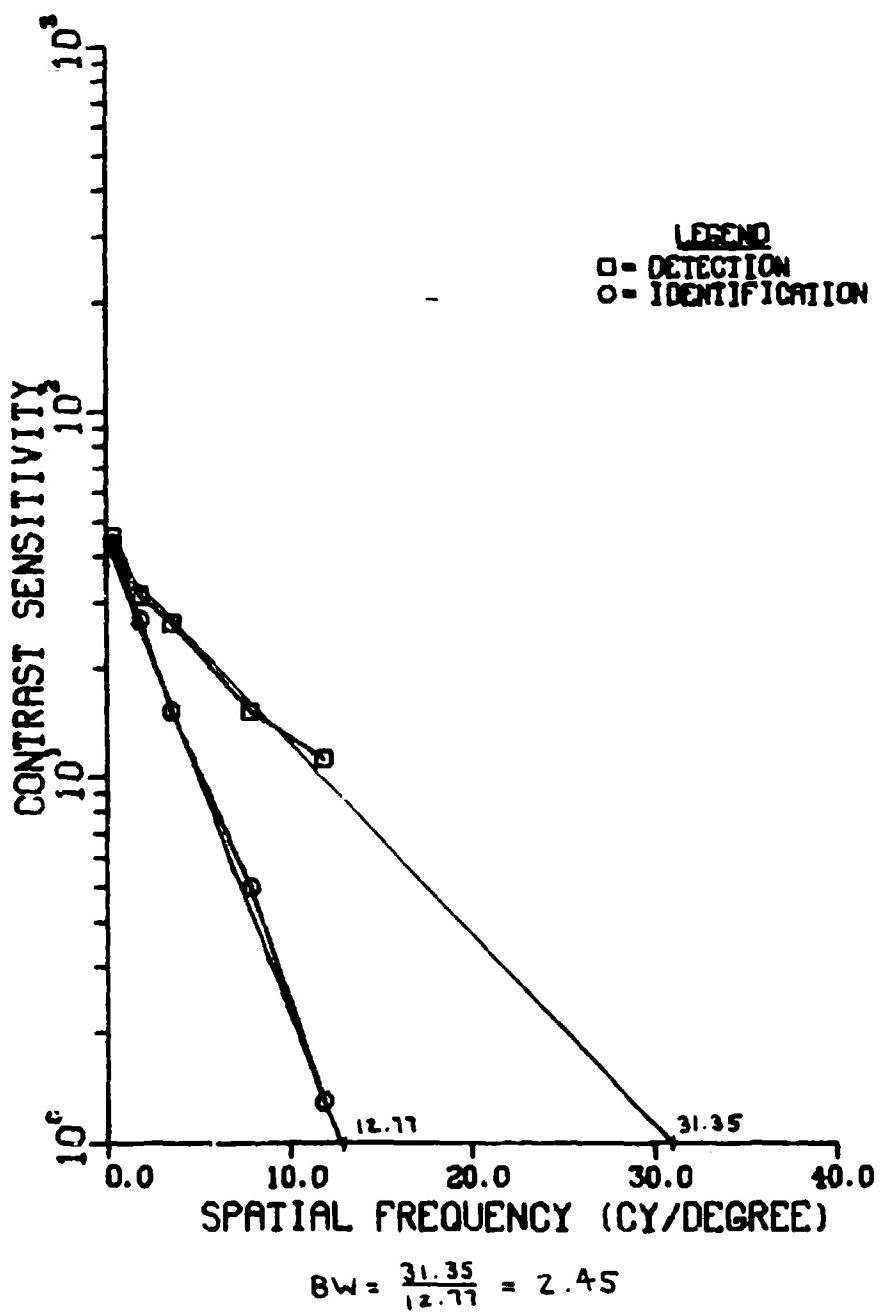


Figure 25. Determination of Bandwidth for Detection and Identification of Snellen Letters

L needed a smaller bandwidth (1.32 cpl) and while the condition of no refractive error required a bandwidth of 1.7 cpl, +3 diopter error required 2.66 cpl.

Accommodation. Accommodation was only measured for the letter E at identification. The accommodation curves for JC and JH are shown in Figures 26 and 27. Both subjects showed less variability than the accommodation curves for the sine-wave gratings. This could be due to the fact that for the E the accommodation measurement was taken at identification, and so was easier to keep in focus. In general, the higher the induced refractive error, the lower the value of the accommodative response.

#### Airplanes

Contrast Sensitivity. Contrast sensitivity functions derived from the identification and detection of aircraft are different from those derived using sine-wave gratings. Since the curves for the three airplanes were very similar only the curves for the F-15 are included in the text. The curves for the MIG-25 and the RA-5C can be found in Appendix B. As can be seen in Figures 28-31, for both JC and JH the detection curves are fairly evenly spaced, with contrast sensitivity decreasing as refractive error increased. As could be predicted from the CSFs from the sine-wave gratings, JH could both detect and identify the airplanes at lower contrast levels than JC.

The identification curves for JH in Figure 31 show that the response to 0 and +1 diopter of refractive error are

MEAN ACCOMMODATION FOR SUBJECT JC  
FOR SNELLEN LETTER E

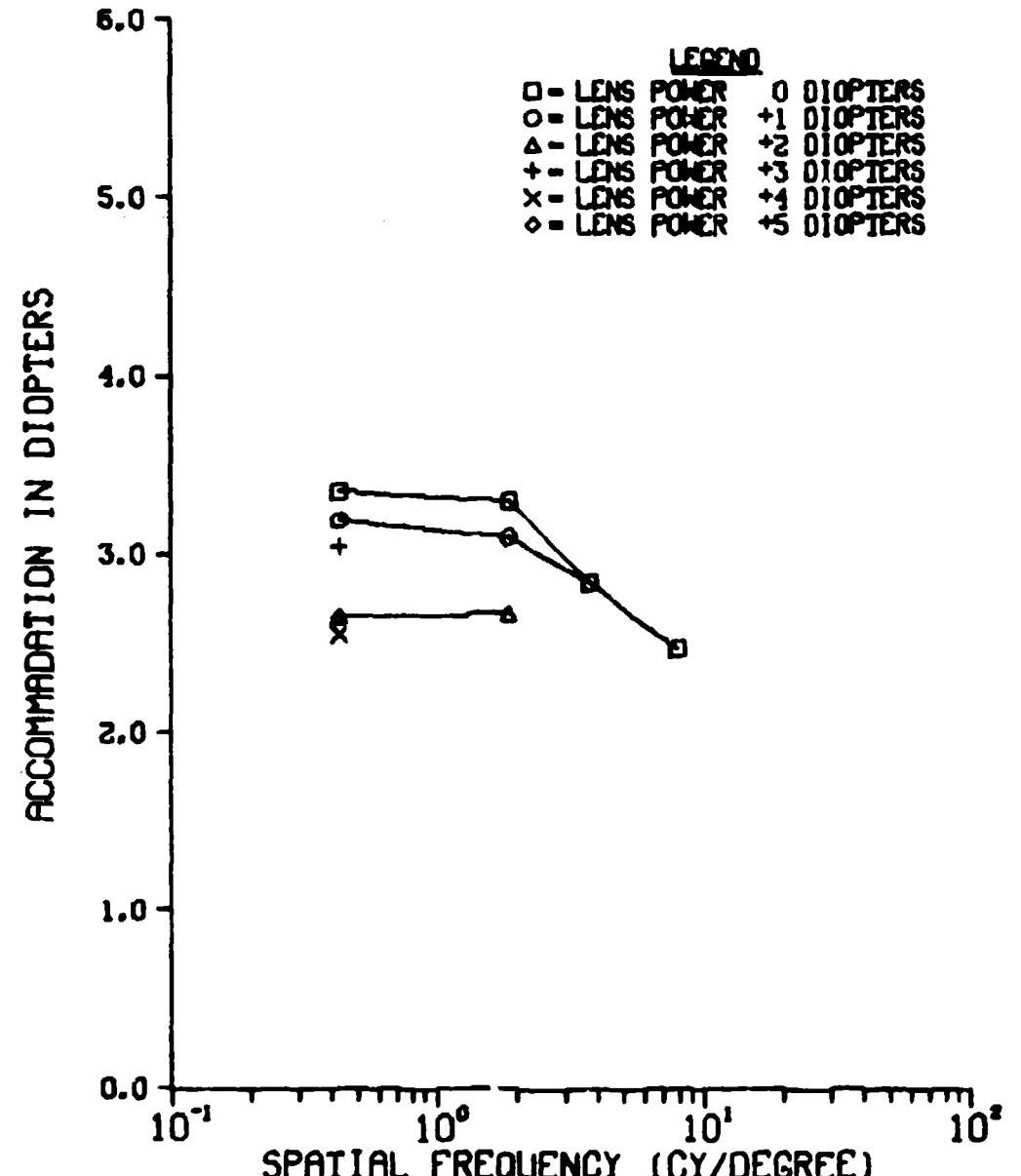


Figure 26. Accommodation for JC for Snellen Letter E Stimuli

## MEAN ACCOMMODATION FOR SUBJECT JH FOR SNELLEN LETTER E

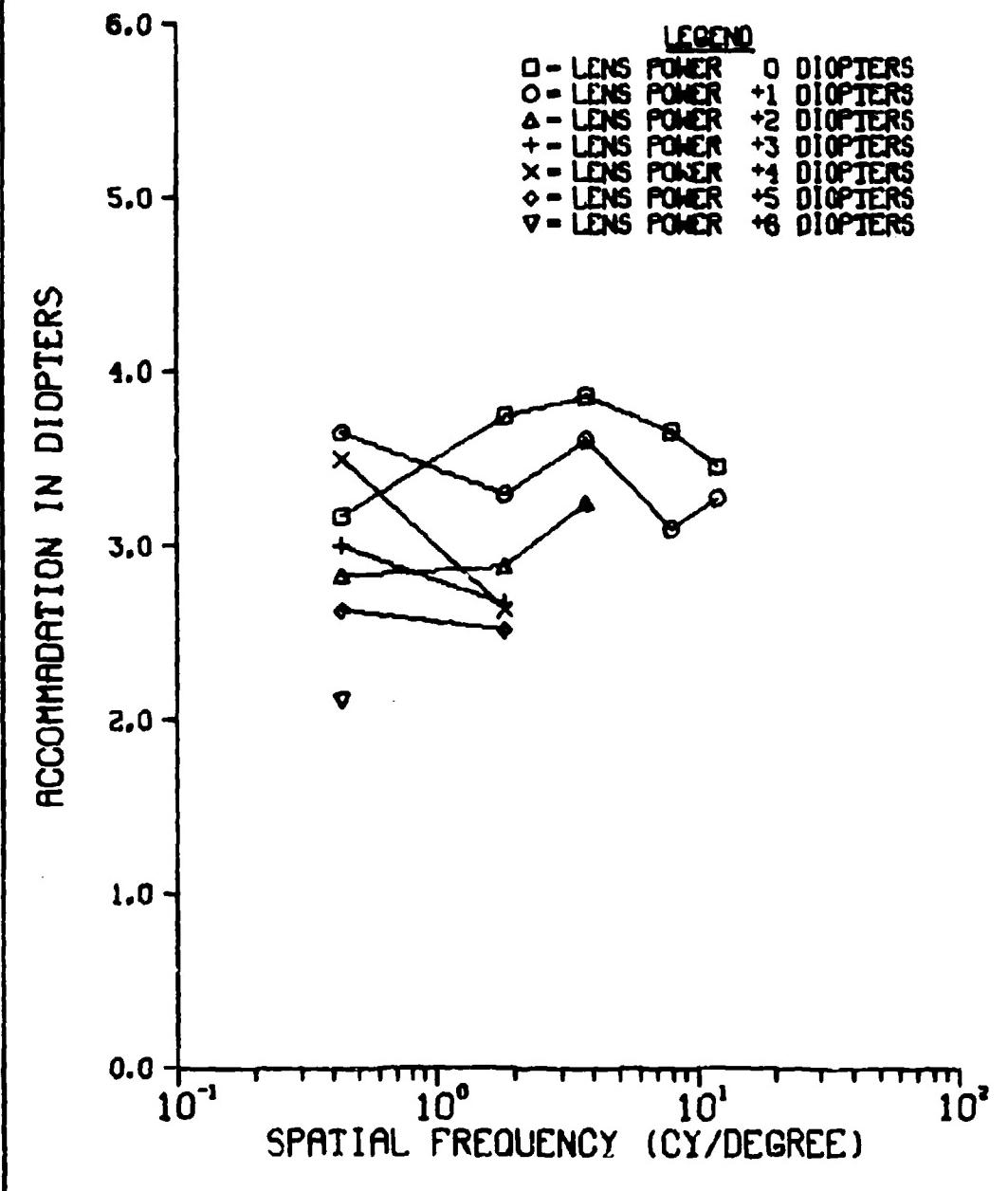


Figure 27. Accommodation for JH for Snellen Letter E Stimuli

# DETECTION OF F 15 AIRCRAFT

FOR SUBJECT JC

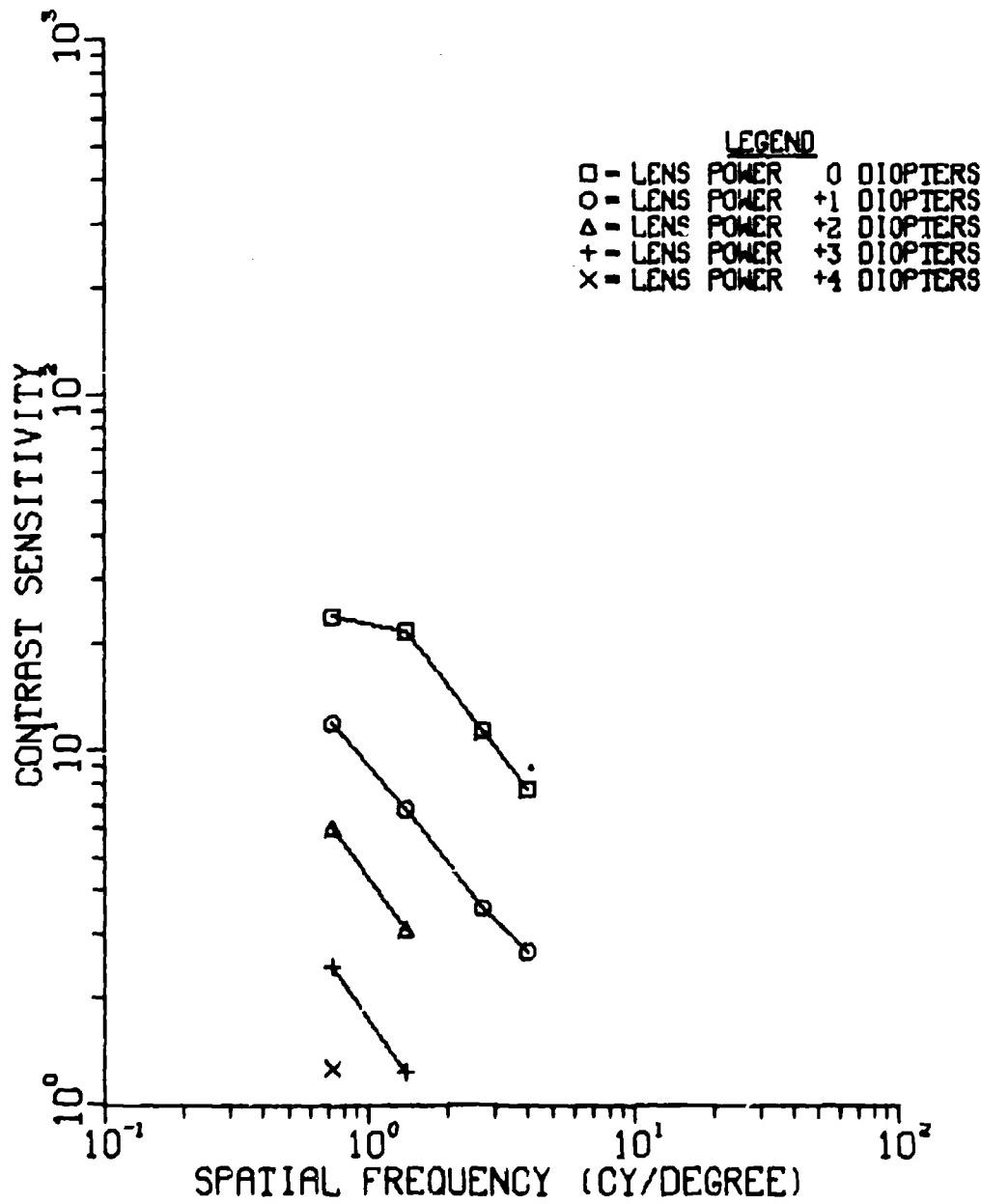


Figure 28. Detection of F-15 for JC

# IDENTIFICATION OF F 15 AIRCRAFT

FOR SUBJECT JC

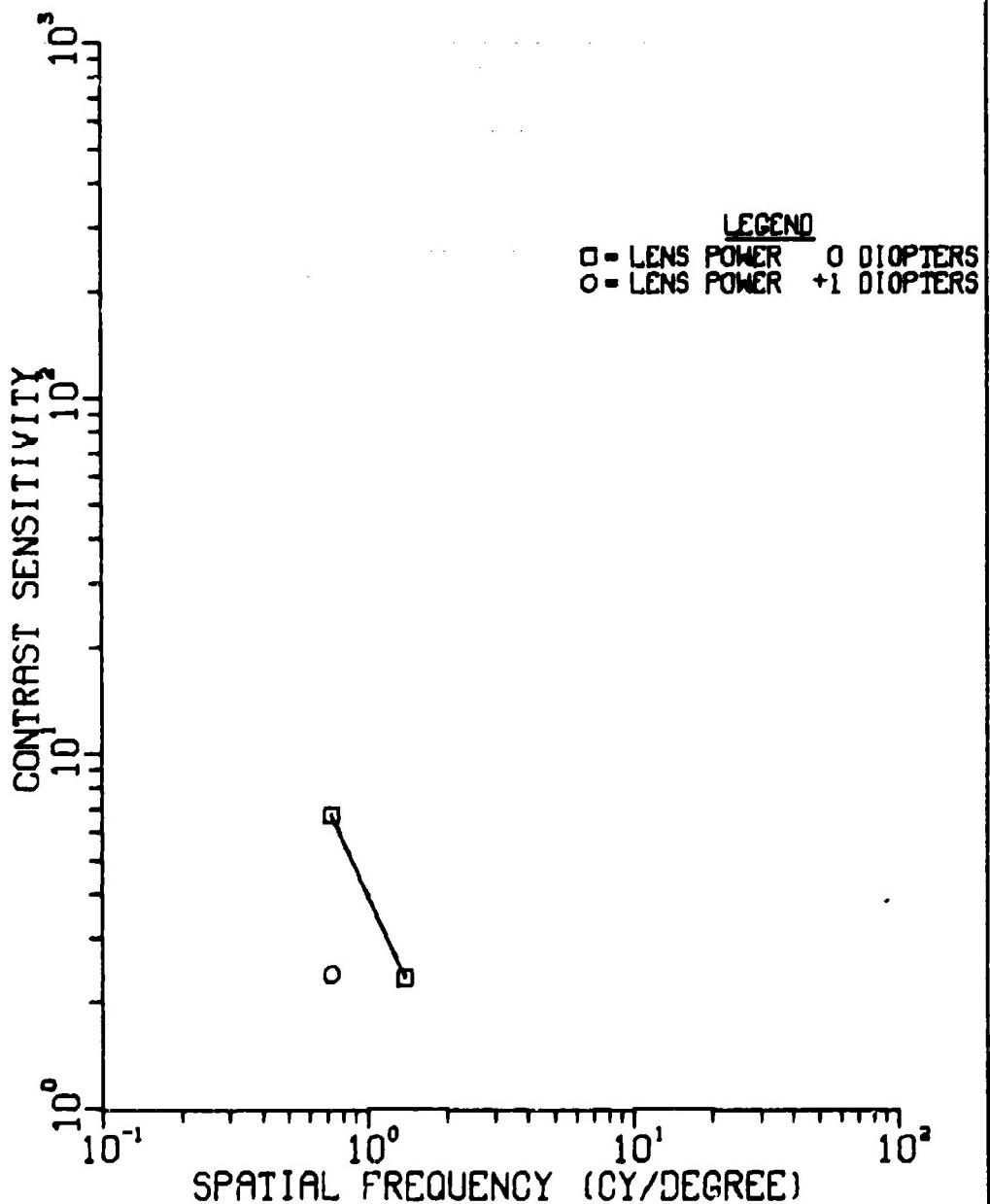


Figure 29. Identification of F-15 for JC

DETECTION OF F 15 AIRCRAFT  
FOR SUBJECT JH

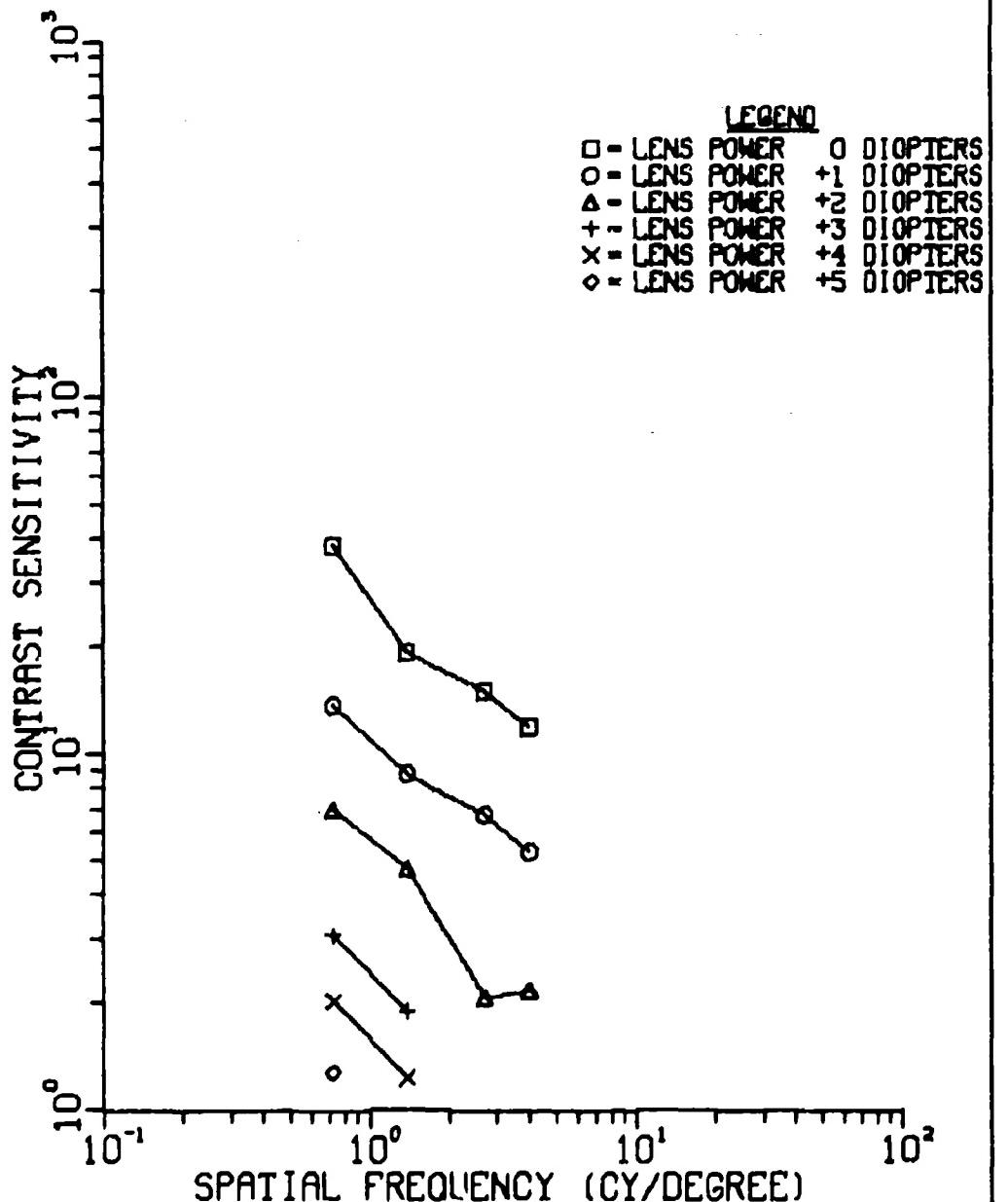


Figure 30. Detection of F-15 for JH

IDENTIFICATION OF F 15 AIRCRAFT  
FOR SUBJECT JH

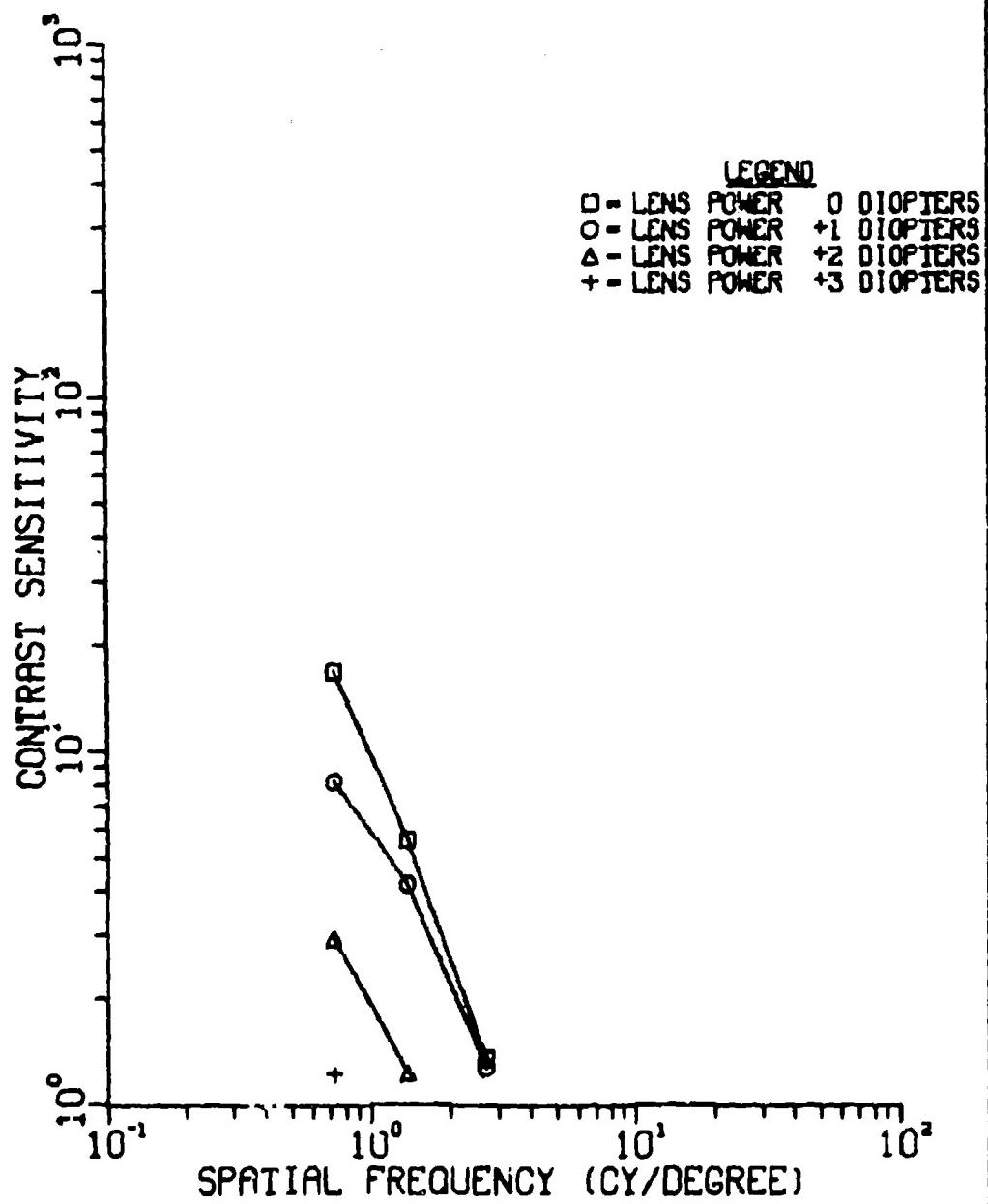


Figure 31. Identification of F-15 for JH

again close, as in the original sine-wave grating CSF. Due to the inability of JC to identify the airplanes at most values of refractive error no conclusions can be drawn from those data.

Accommodation. Accommodation measurements were again taken only at identification contrast and only for the F-15. These plots are shown in Figures 32 and 33. The small number of points make it difficult to draw any conclusions but the mean values of accommodation do agree with those from the sine-wave gratings and Snellen letter E.

#### Low Luminance Tests

A plot of the CSFs for JC under low illumination derived using sine-wave gratings is shown in Figure 34. It can be seen that with no refractive error, a drop in the illumination by a factor of 10 had no effect on CSFs. Another finding was that a blur of +2 diopter required less contrast than a drop in luminance of 1000 times. The same was true in going from +2 to +4 diopter, the extra refractive error was preferable to a further drop in luminance. These results suggest that large reductions in luminance have a more deleterious affect on contrast sensitivity than moderate (+2 diopter) blur. It should be noted though, that a drop in luminance of 1000 times with no refractive error required less contrast than an error of +4 diopter.

For the Snellen letters E and B detection and identification at +2 diopter error with an ND2 filter (100

MEAN ACCOMMODATION FOR SUBJECT JC  
FOR F 15 AIRCRAFT

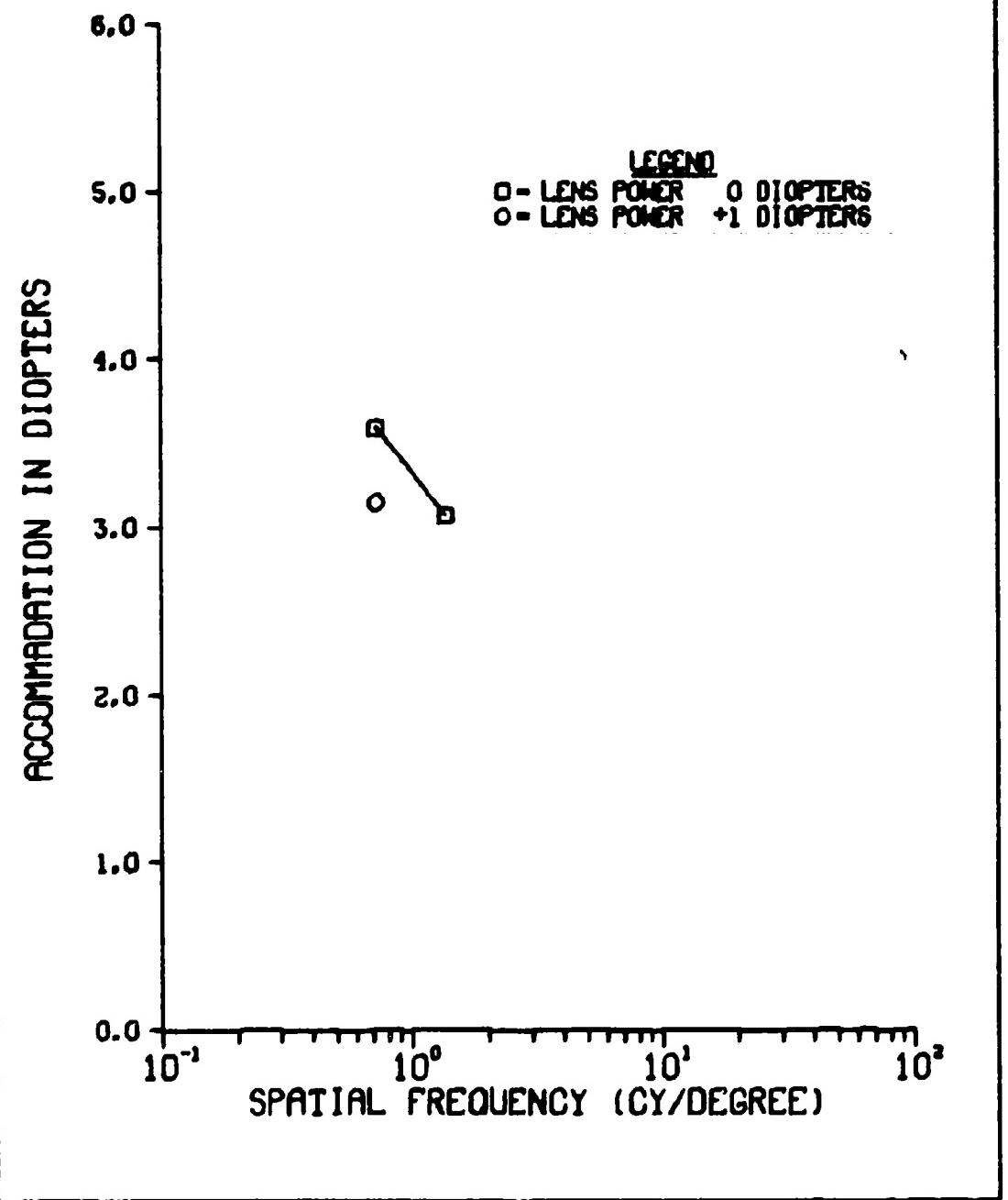


Figure 32. Accommodation for JC for F-15 Stimuli

# MEAN ACCOMMODATION FOR SUBJECT JH FOR F 15 AIRCRAFT

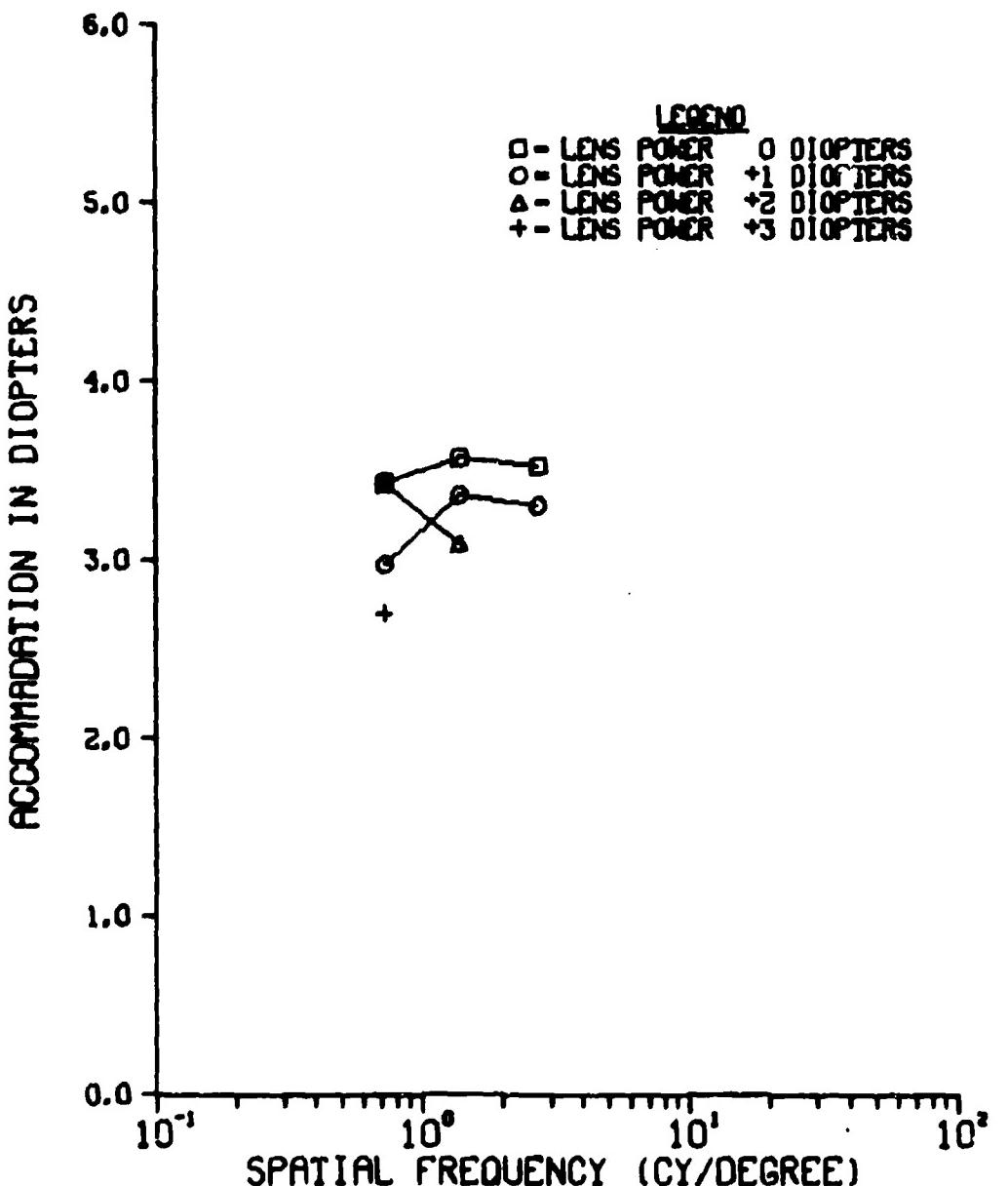


Figure 33. Accommodation for JH for F-15 Stimuli

CONTRAST SENSITIVITY FOR SUBJECT JC  
FOR SINE-WAVE GRAINGS

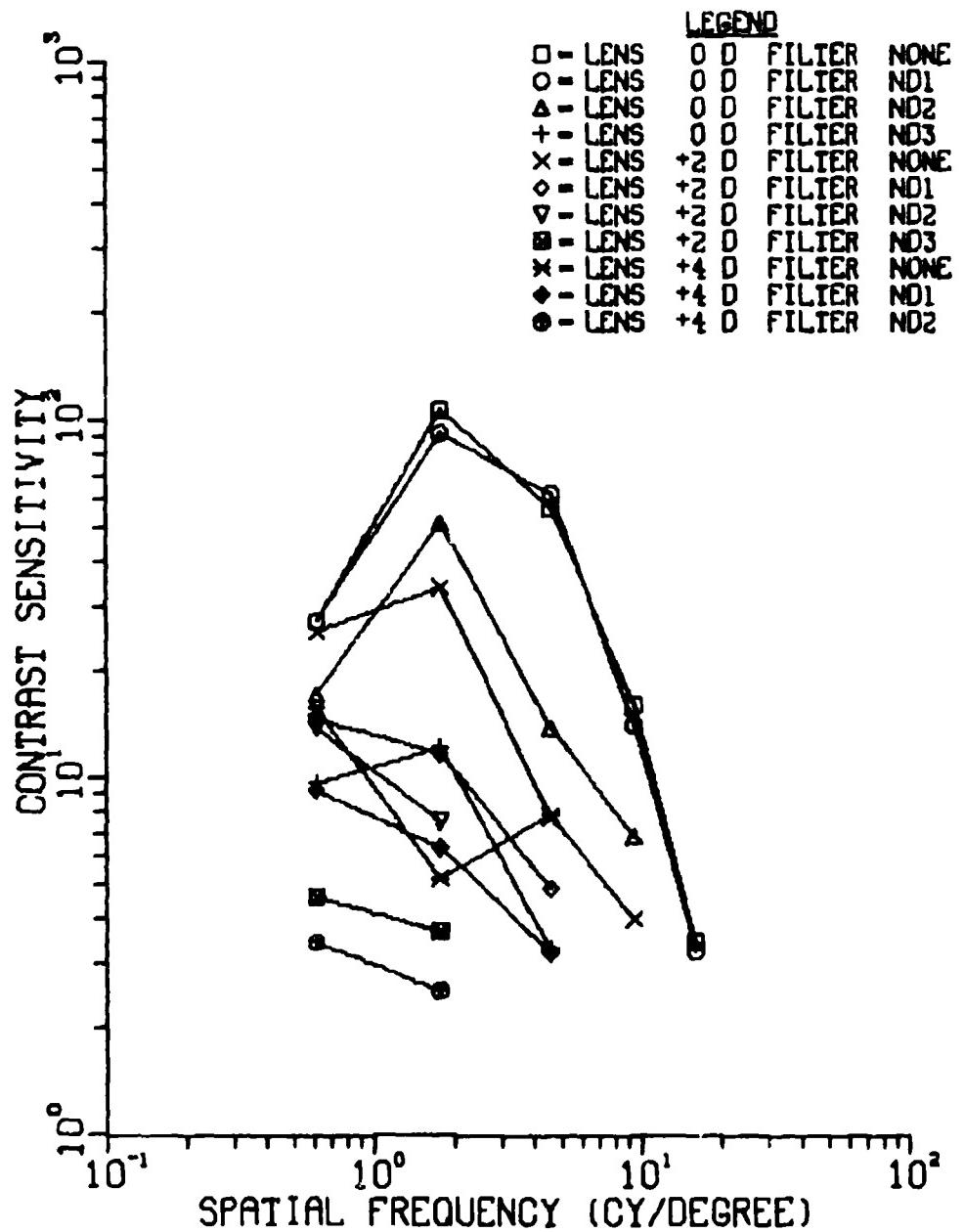


Figure 34. CSF for JC Under Low Luminance Conditions  
for Sine-Wave Grating Stimuli

times drop in luminance) required less contrast than performing the same task with no error at a 1000 times reduction of luminance. These results for the letter E are shown in Figures 35 and 36. The plots for the letter B appear in Appendix B.

For the MIG-25 and F-15 aircraft both the detection and identification curves showed a steady drop in contrast sensitivity with increasing ND filters. This can be seen for the F-15 in Figures 37 and 38. The results for the MIG-25 are in Appendix B. With +2 diopter blur and an ND 1 filter not even the largest airplane (.65 cy/d spatial frequency) could not be recognized.

## DETECTION OF SNELLEN LETTER E

FOR SUBJECT JC

### LEGEND

□ - LENS	○ D FILTER	NONE
○ - LENS	○ D FILTER	ND1
△ - LENS	○ D FILTER	ND2
+ - LENS	○ D FILTER	ND3
✗ - LENS	+2 D FILTER	NONE
◇ - LENS	+2 D FILTER	ND1
▽ - LENS	+2 D FILTER	ND2
■ - LENS	+2 D FILTER	ND3
✗ - LENS	+4 D FILTER	NONE
◆ - LENS	+4 D FILTER	ND1
● - LENS	+4 D FILTER	ND2
■ - LENS	+4 D FILTER	ND3

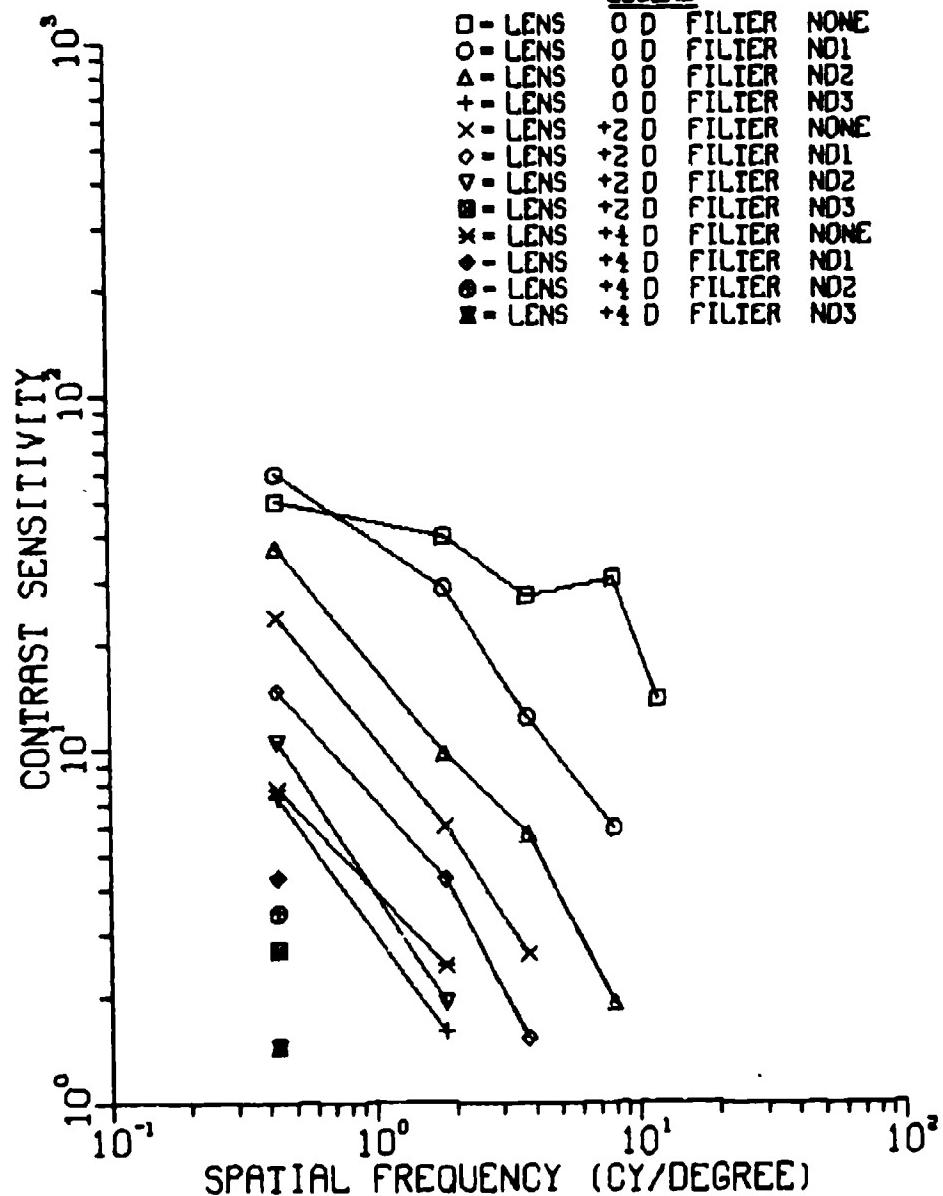


Figure 35. Detection of E for JC Under Low Luminance Conditions

# IDENTIFICATION OF SNELLEN LETTER E

FOR SUBJECT JC

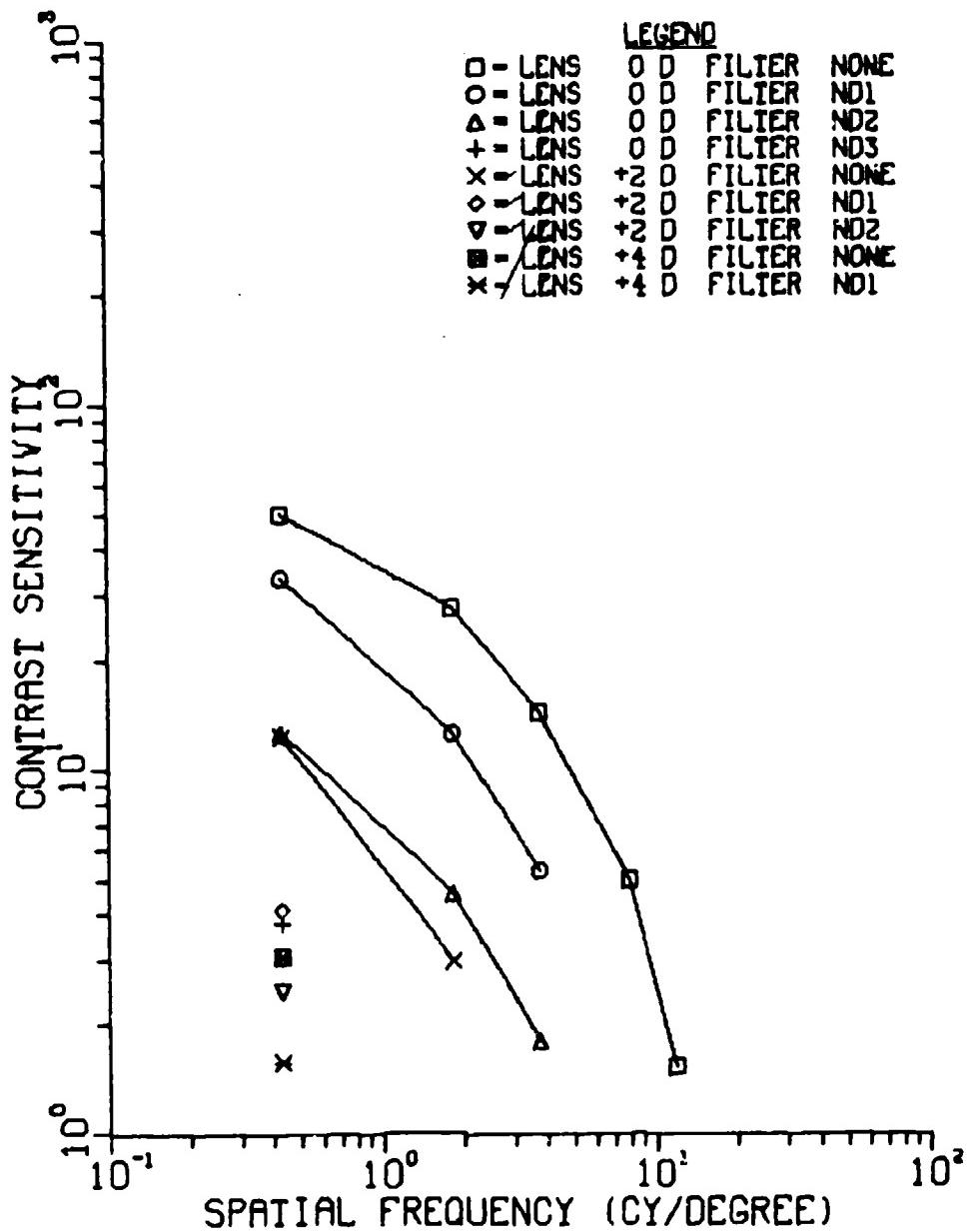


Figure 36. Identification of E for JC Under Low Luminance Conditions

# DETECTION OF F 15 AIRCRAFT

FOR SUBJECT JC

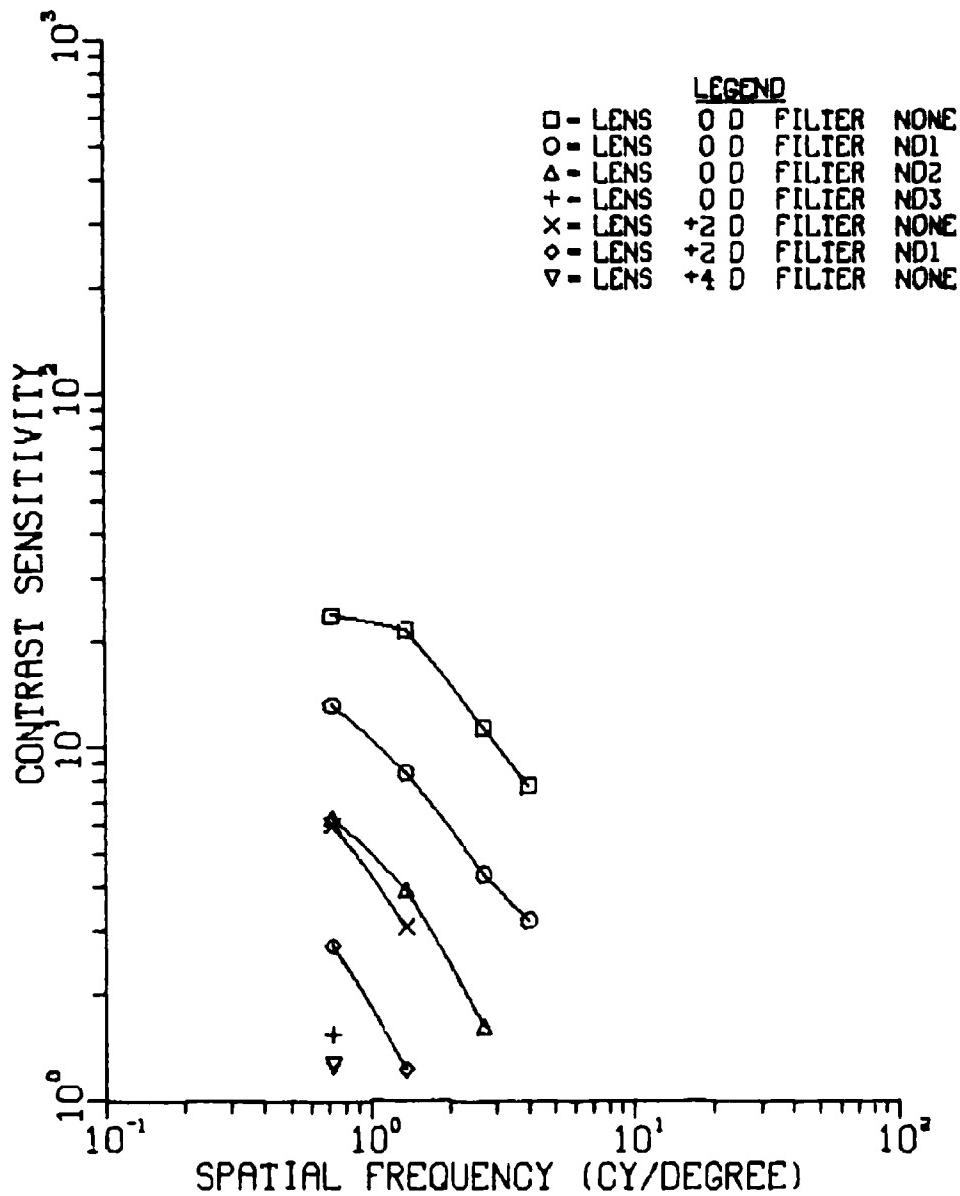


Figure 37. Detection of F-15 for JC Under Low Luminance Conditions

IDENTIFICATION OF F 15 AIRCRAFT  
FOR SUBJECT JC

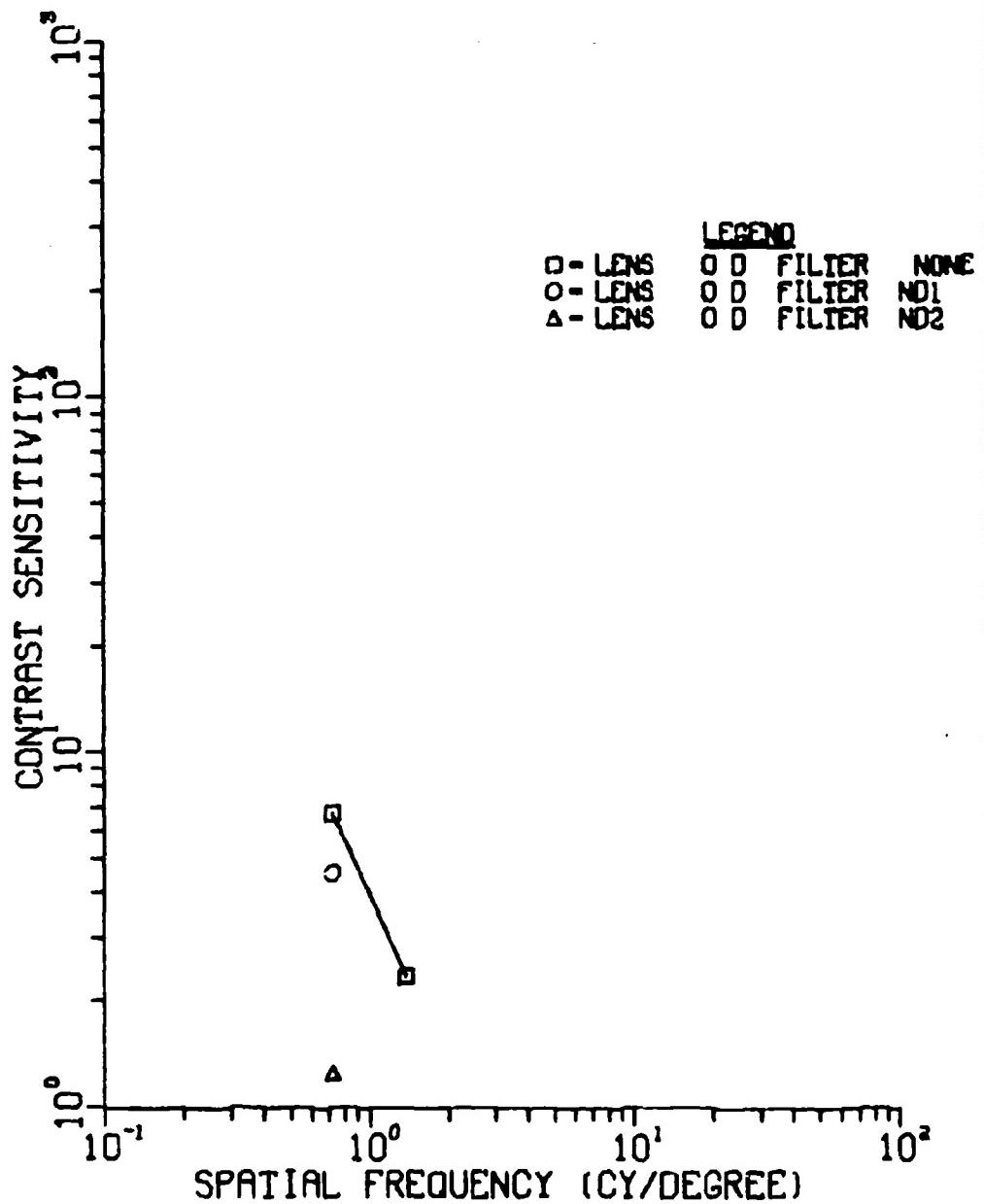


Figure 38. Identification of F-15 for JC Under Low Luminance Conditions

## V. Conclusions

Refractive error did degrade the contrast sensitivity response of the human visual system as expected. This degradation could be seen in the CSFs derived using sine-wave gratings, letters, and airplanes. The response curves for the Snellen letters and the airplanes followed the same general pattern as the curves derived using sine-wave gratings as the stimulus.

The accommodation measurements from the sine-wave gratings did not show any specific trend. Those from the letter E and the F-15 aircraft showed a reduction in accommodation, i.e. an attempt to flatten the lens in the eye to try to keep the image in focus, with increasing induced refractive error.

The low luminance study showed that a small (times 10) reduction in luminance did not have an affect on the contrast needed for sine-wave gratings, but it did affect the identification of letters and airplanes. A reduction of luminance of 100 times had noticeable affects in all three tests and a reduction of 1000 times had profound effects.

## VI. Recommendations

There is a need for a larger data base to determine the average effects of refractive error. To get a larger data base, the time required to measure accommodation must be shortened. This could be done by using a different type of laser optometer incorporating prisms to avoid time consuming drum movements.

An experiment exploring the effects of changes in contrast on accommodation would also be useful in determining the minimum contrast necessary to get a stable accommodation measurement.

The low luminance experiments done in this thesis can only be considered preliminary and should be continued to further explore these findings.

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13. Charman, W. N. "On the Position of the Plane of Stationarity in Laser Refraction," American Journal of Optometry and Physiological Optics, 51:832-838, (1974).

## APPENDIX A

### Plane of Stationarity for the Badal Optometer

Charman (Ref 12) showed that the plane of stationarity of the speckle pattern produced by the laser optometer is not necessarily the frontal plane of the drum of the optometer (See Figure 6). The plane of stationarity depends on the drum radius, the distance from the laser light to the drum, and the angle of the light impinging on the drum. It is necessary to determine the plane of stationarity because it is the distance to the plane of stationarity and not just the drum surface itself, which determines the accommodation in Equation 2.

The equation for determining the plane of stationarity, as derived by Charman is:

$$x = \frac{r[R(\cos a + r)]}{R(1 + \cos a) + r} \quad (3)$$

where  $r$  is the drum radius,  $R$  is the distance from the laser light to the drum (from the final mirror), and  $a$  is the angle of incidence of the laser light on the drum.

For the optometer used in my experiments,  $r$  was 3.3 cm,  $R$  was 11.1 cm and  $a$  was 95 degrees. This yields a plane of stationarity at .57 cm behind the drum surface. This was taken into account on all accommodation calculation.

## APPENDIX B

Appendix B contains those plots of the results that  
were not included in the text.

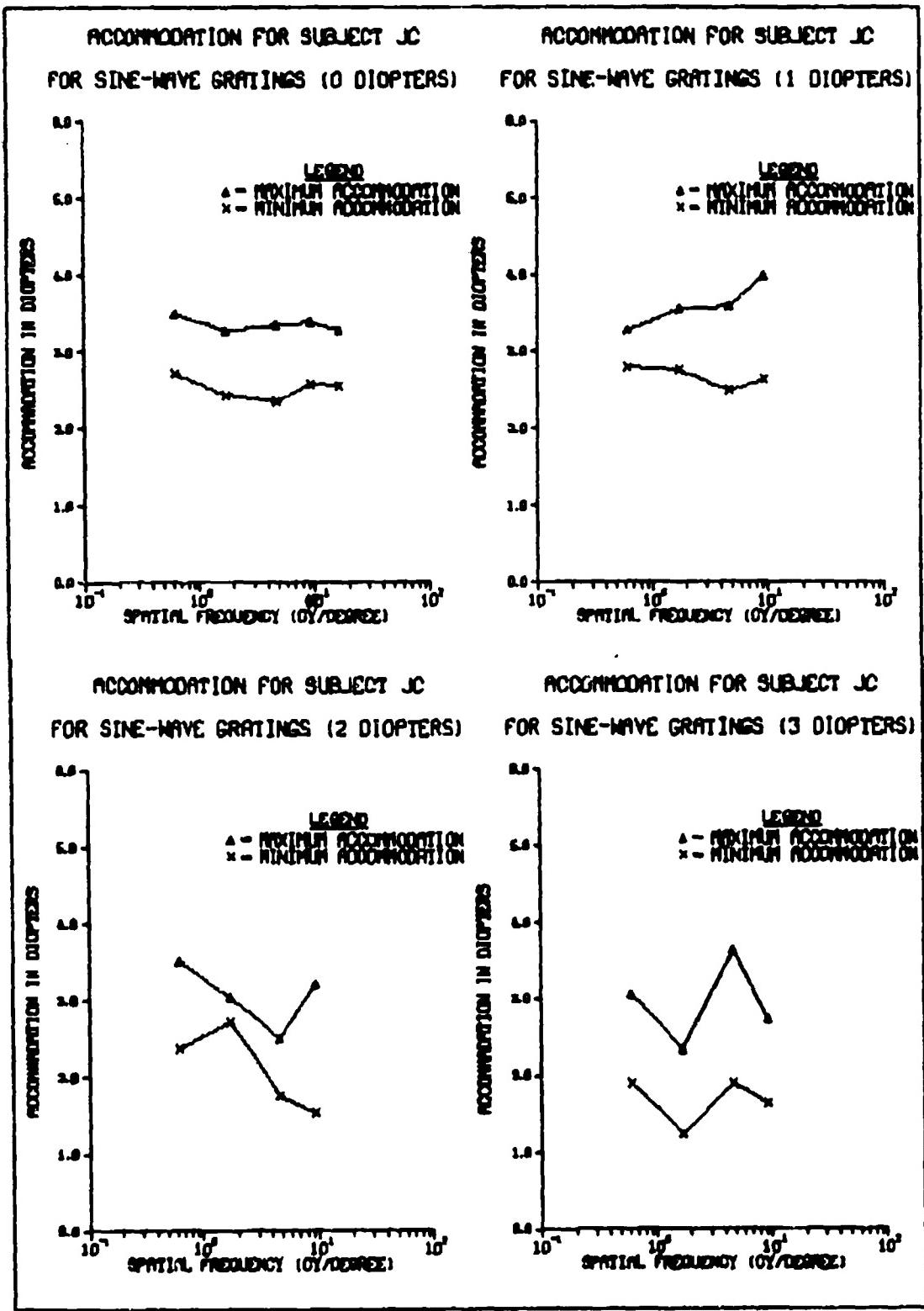


Figure 39. Accommodation for JC for Sine-Wave Grating Stimuli

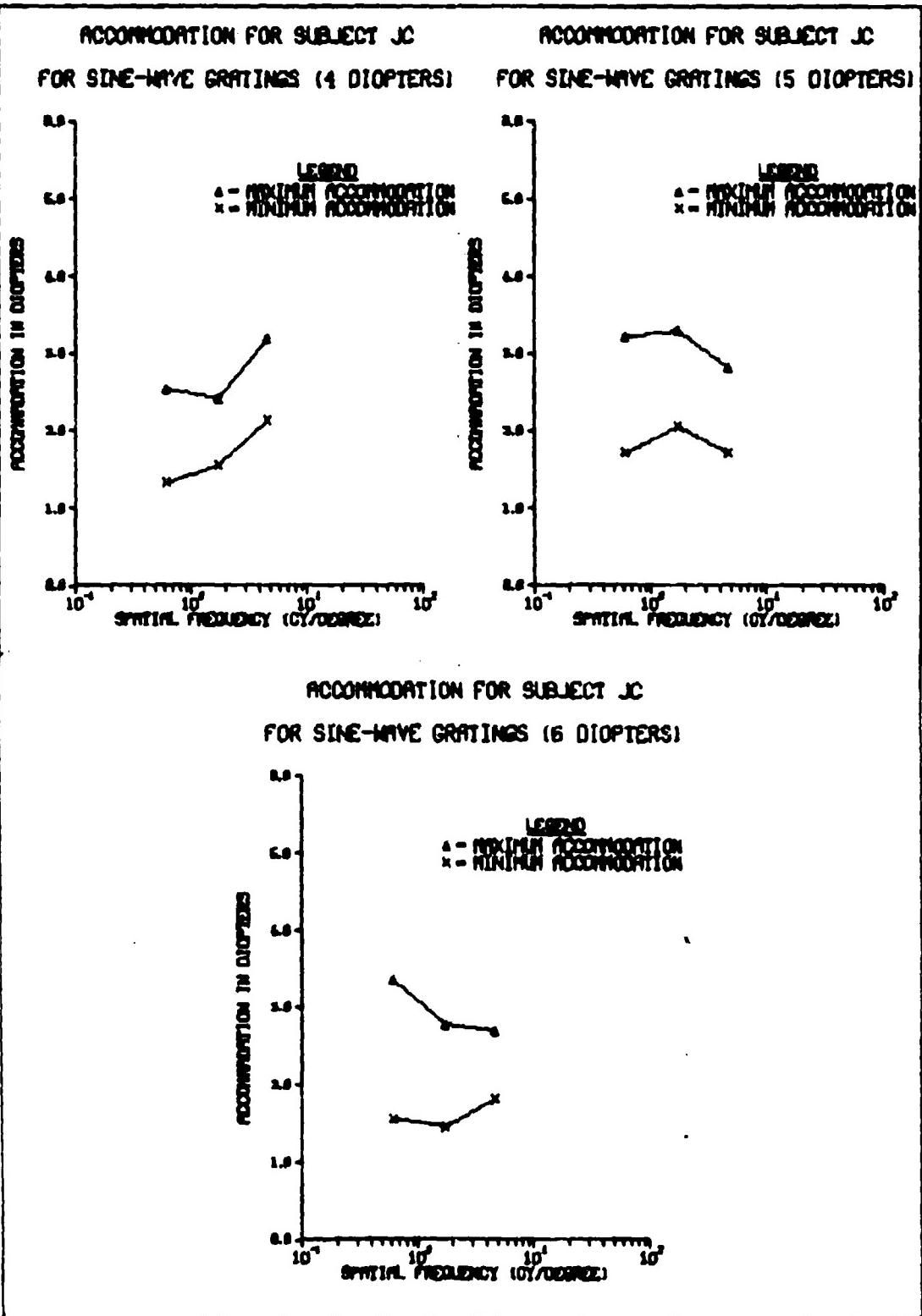


Figure 39 (Cont.) Accommodation for JC for Sine-Wave Grating Stimuli

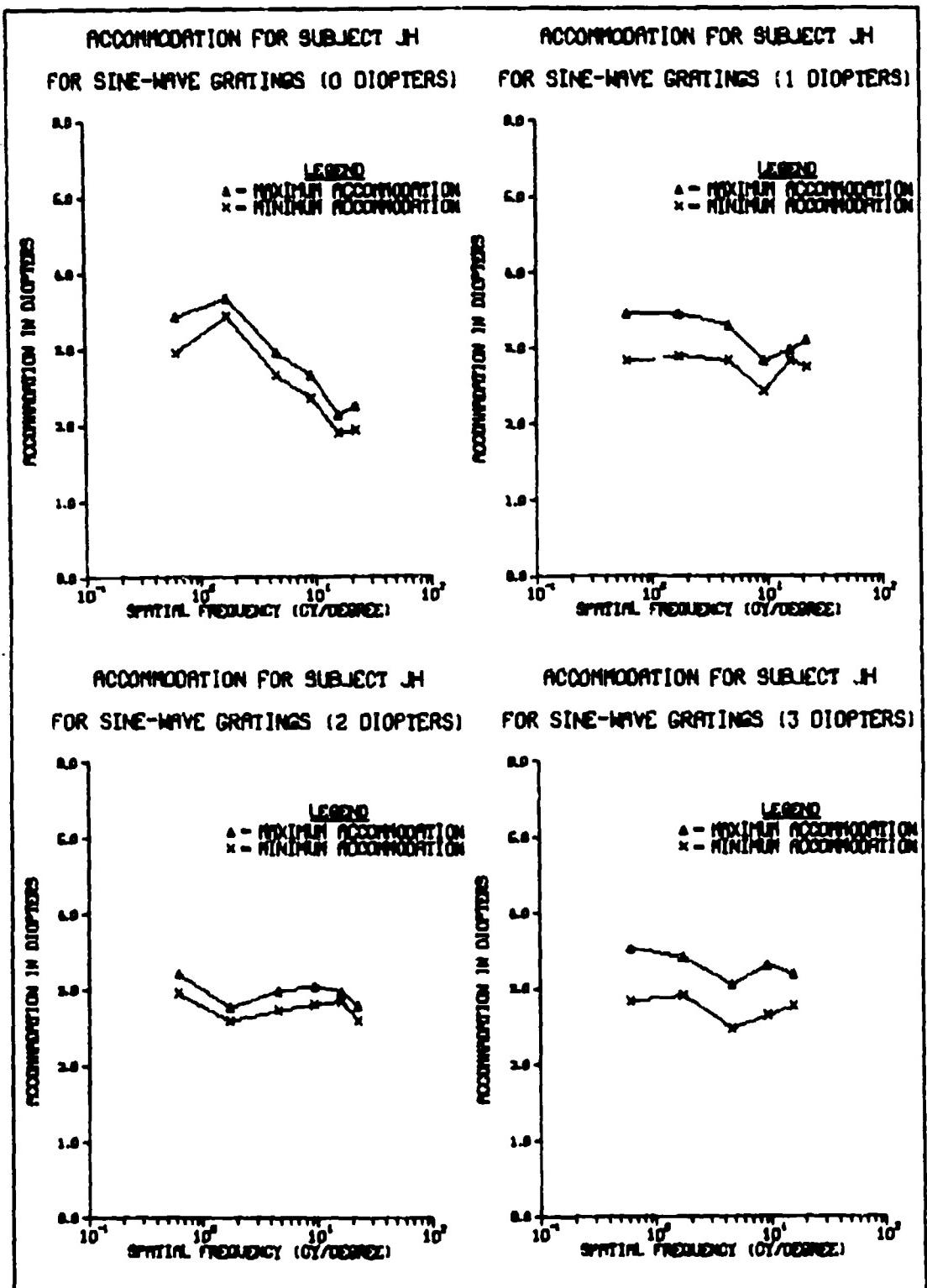


Figure 40. Accommodation for JH for Sine-Wave Grating Stimuli

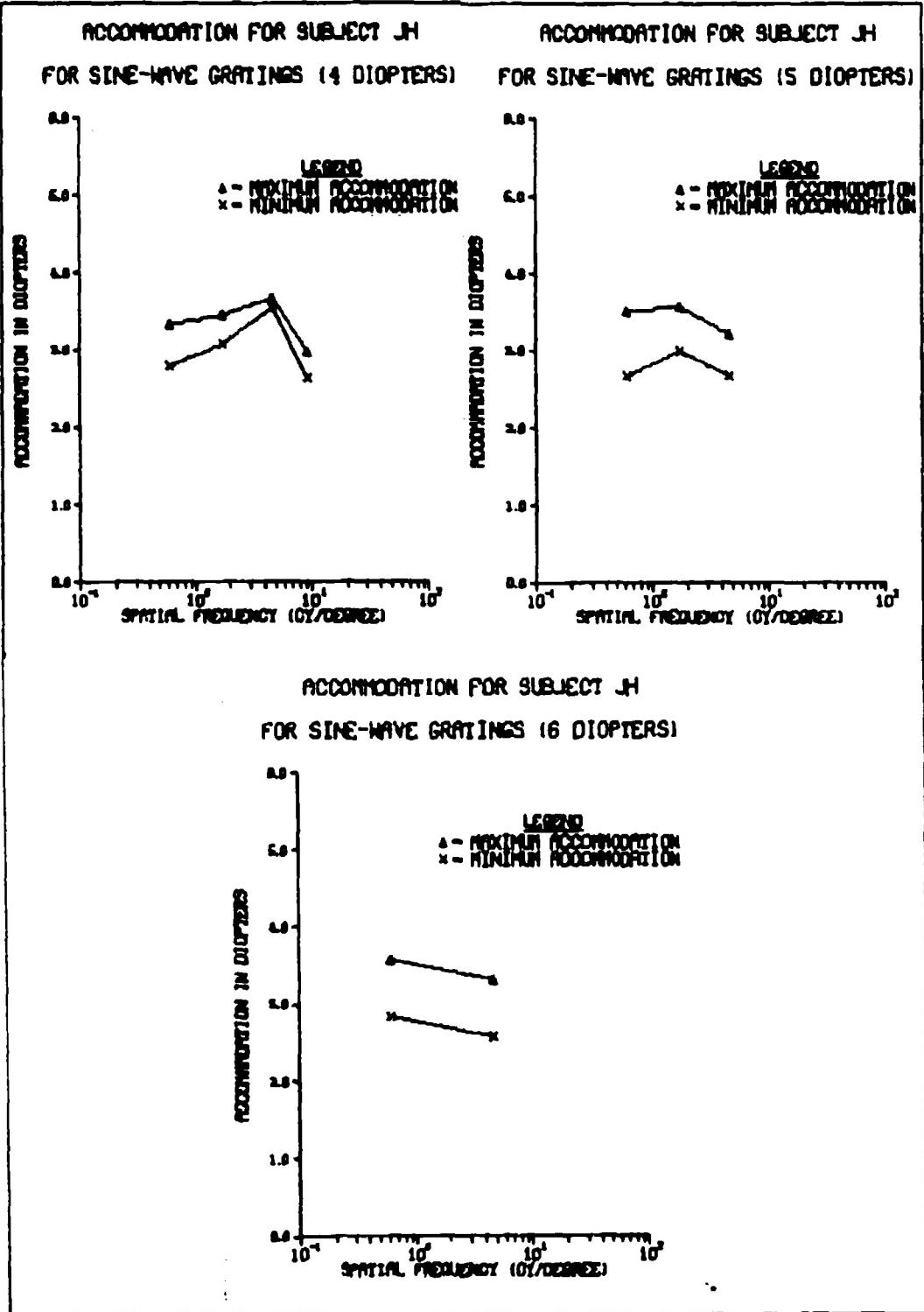


Figure 40 (Cont.) Accommodation for JH for Sine-Wave Grating Stimuli

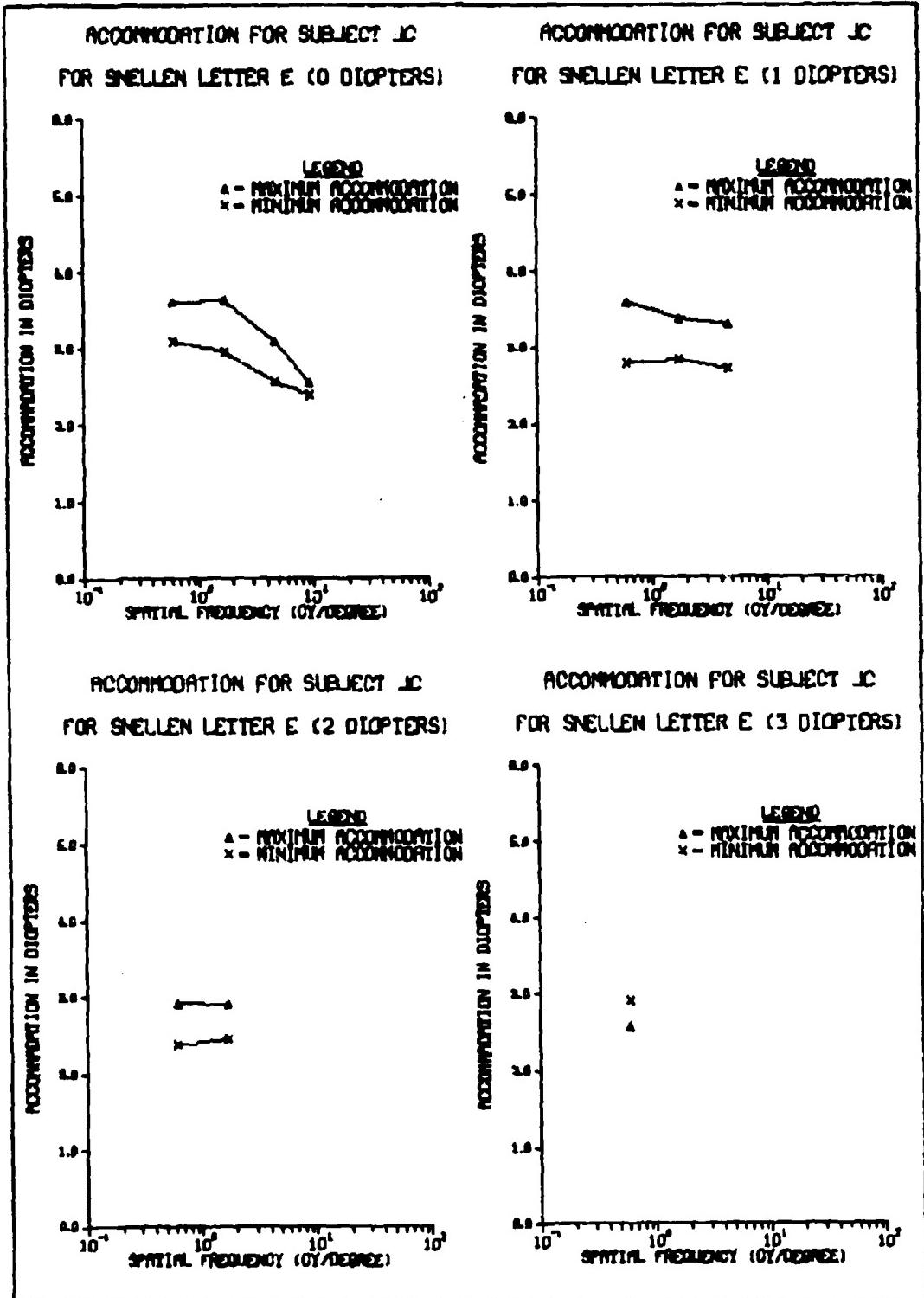


Figure 41. Accommodation for JC for Snellen Letter E

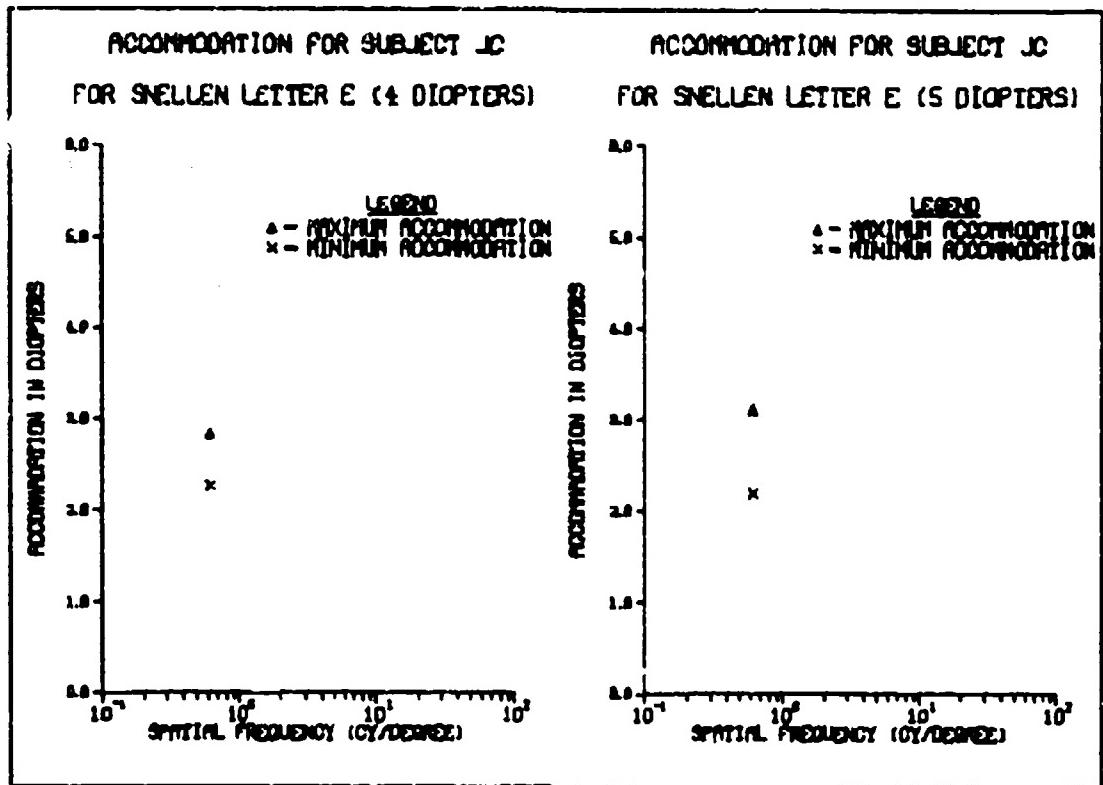


Figure 41(cont.). Accommodation for JC for Snellen Letter E

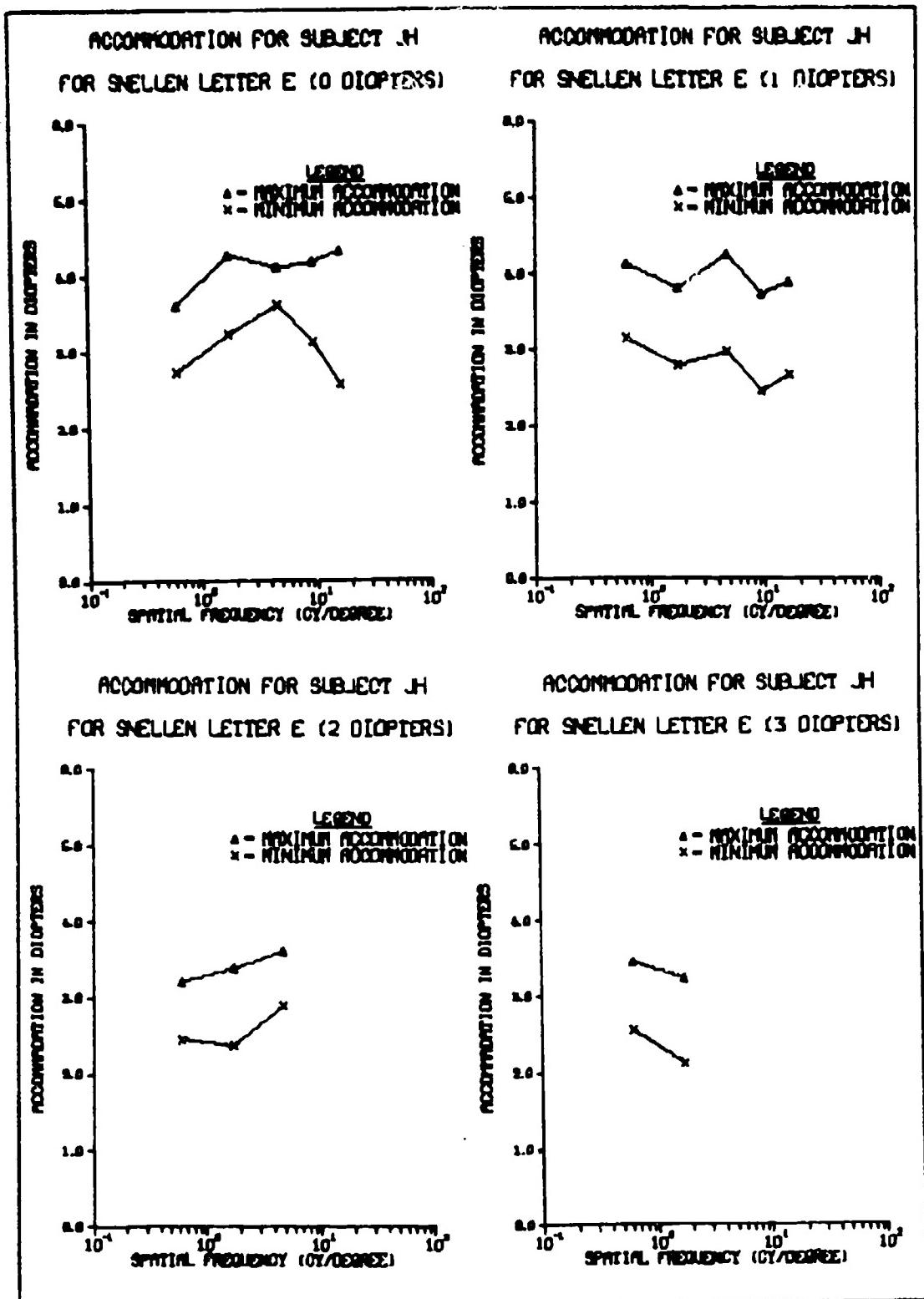


Figure 42. Accommodation for JH for Snellen Letter E

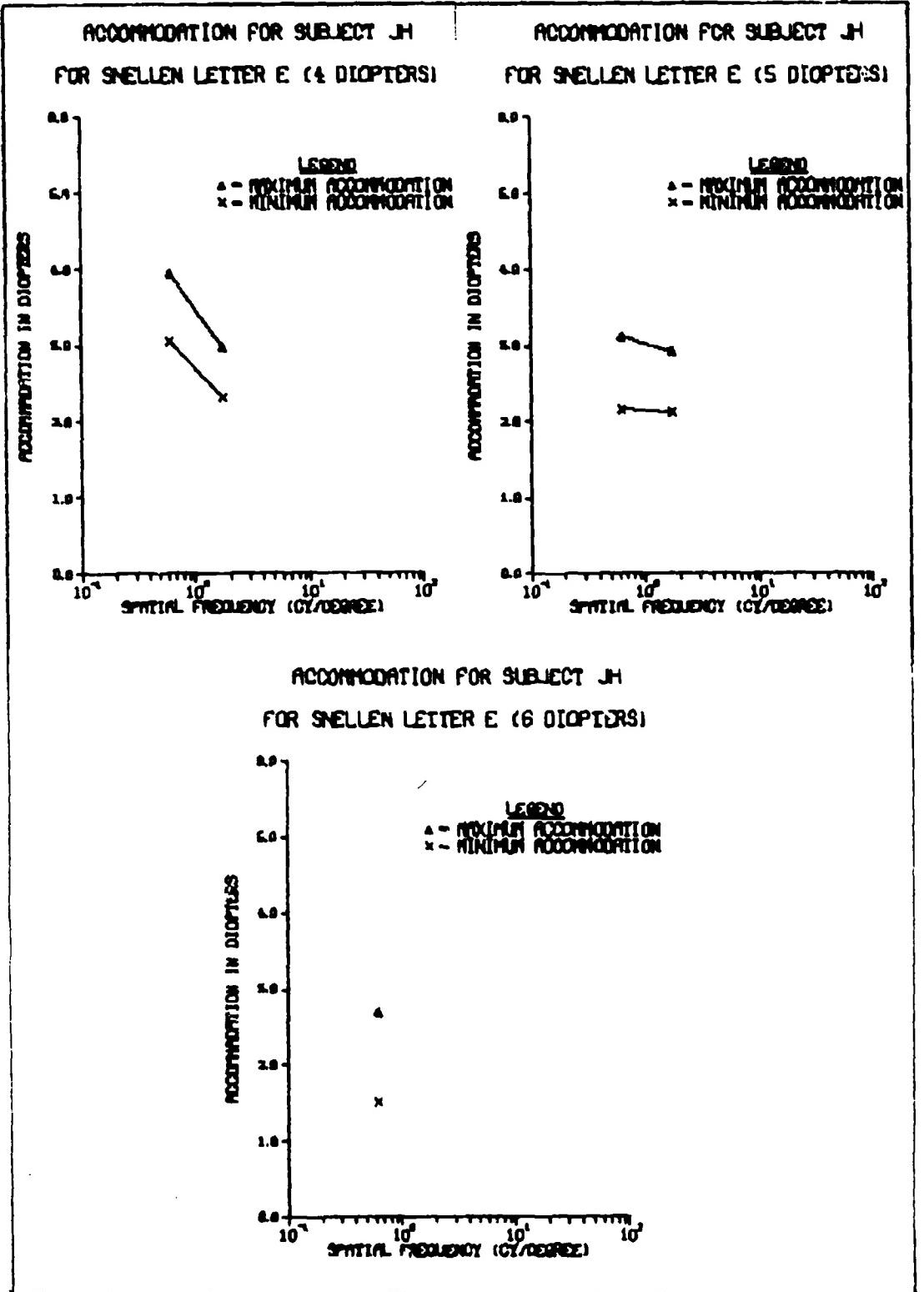


Figure 42(cont.). Accommodation for JH for Snellen Letter E

## DETECTION OF MIG 25 AIRCRAFT

FOR SUBJECT JC

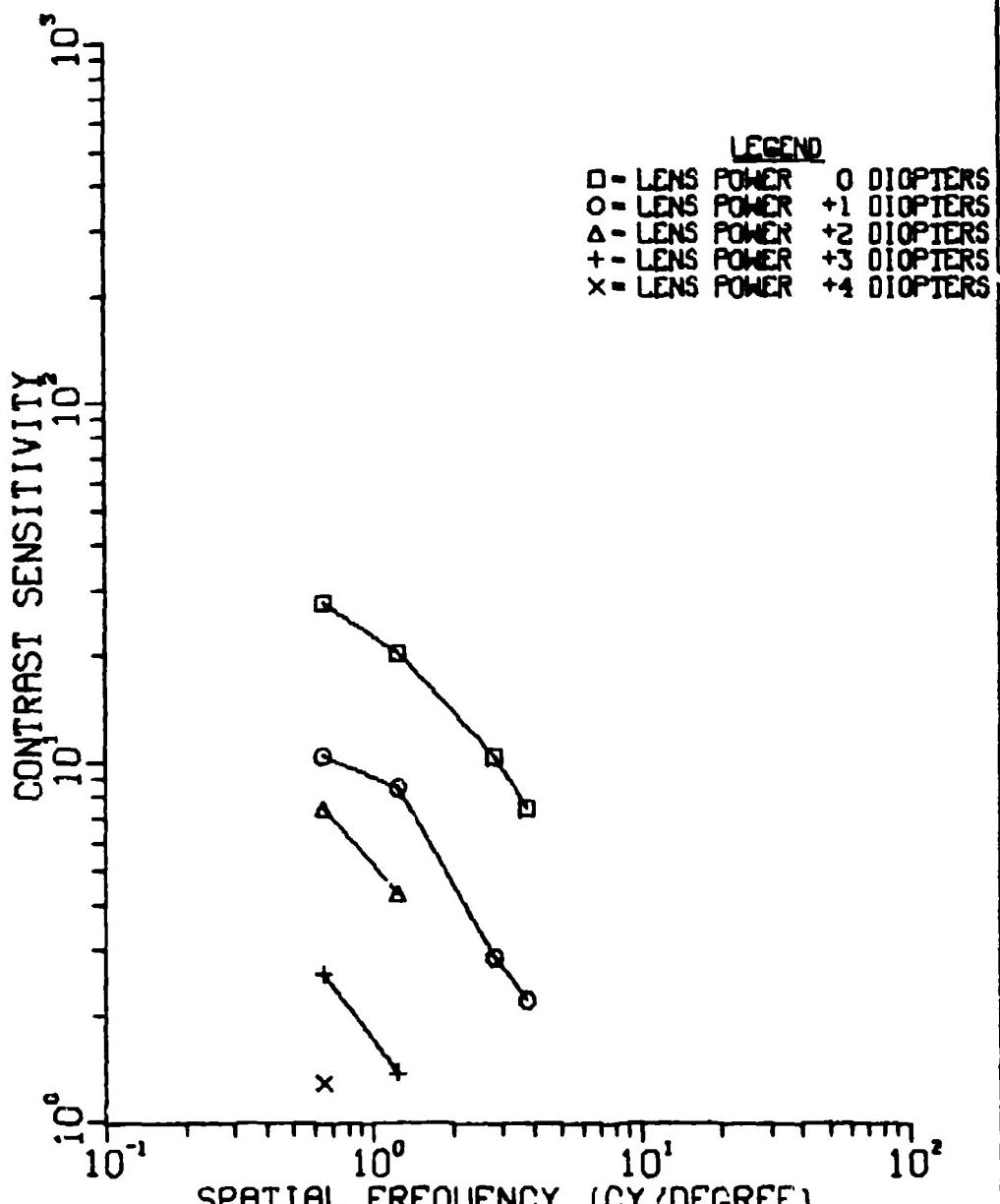


Figure 43. Detection of MIG-25 for JC

## DETECTION OF RA 5C AIRCRAFT

FOR SUBJECT JC

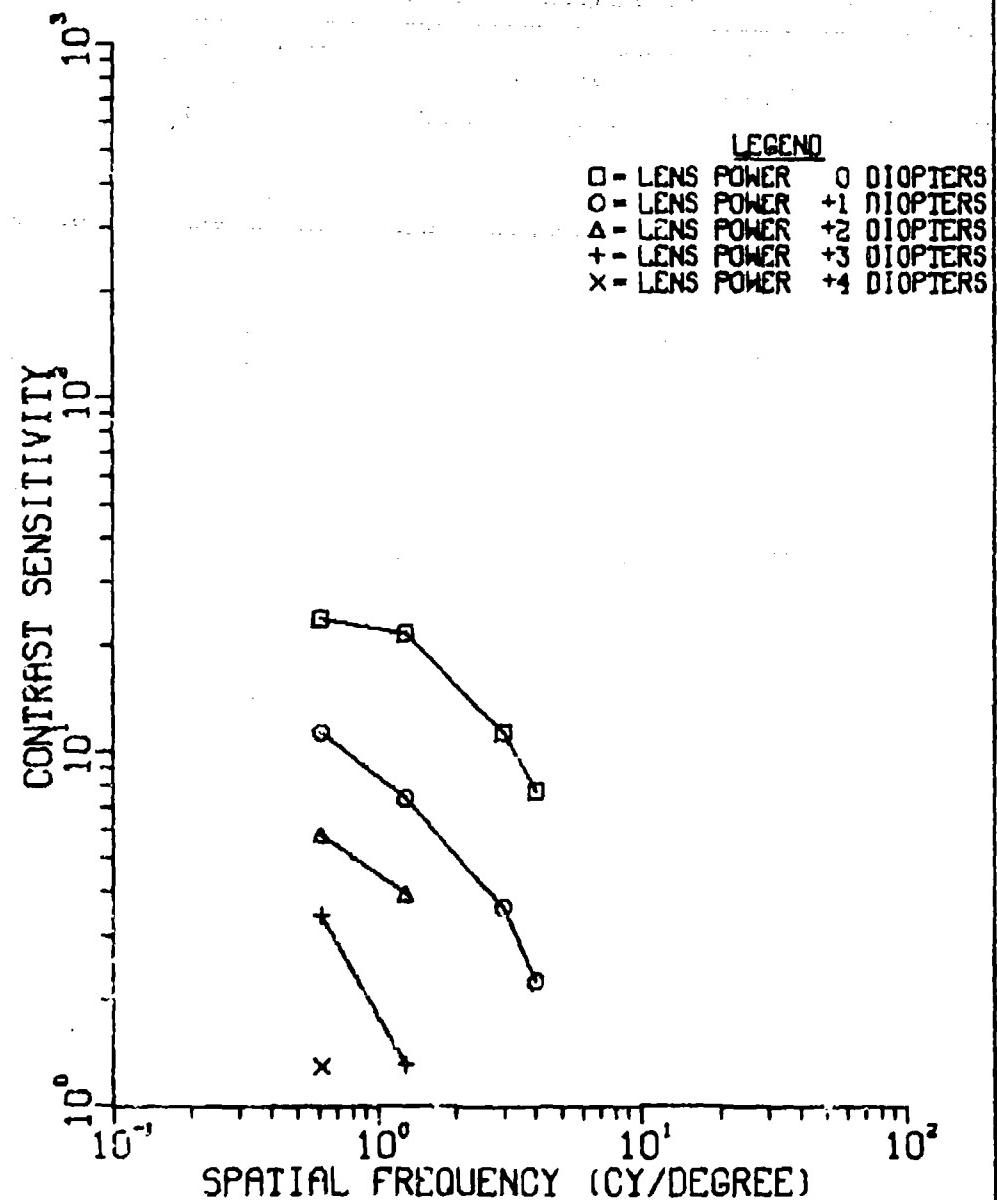


Figure 44. Detection of RA-5C for JC

IDENTIFICATION OF MIG 25 AIRCRAFT  
FOR SUBJECT JC

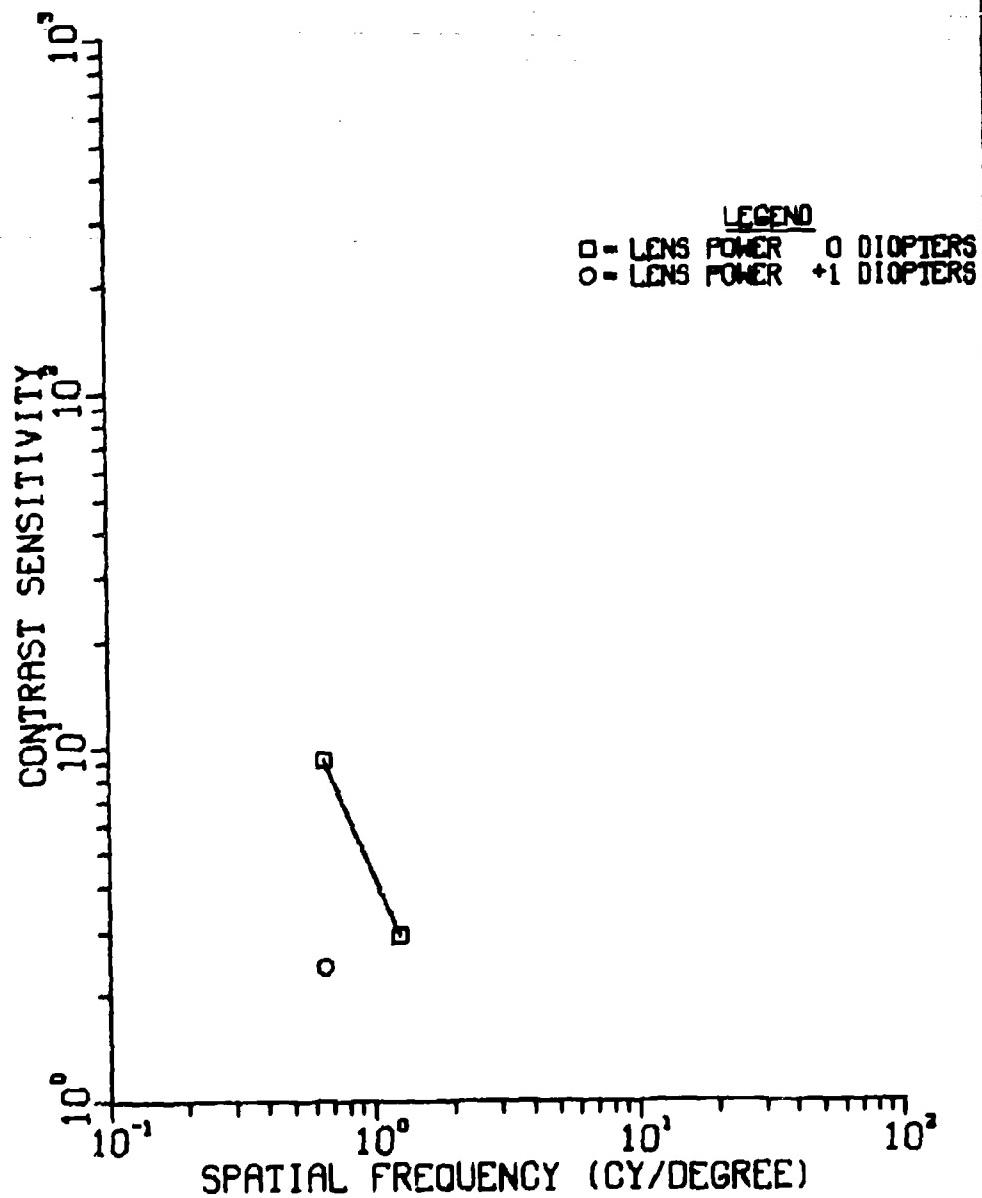


Figure 45. Identification of MIG-25 for JC

IDENTIFICATION OF RA 5C AIRCRAFT  
FOR SUBJECT JC

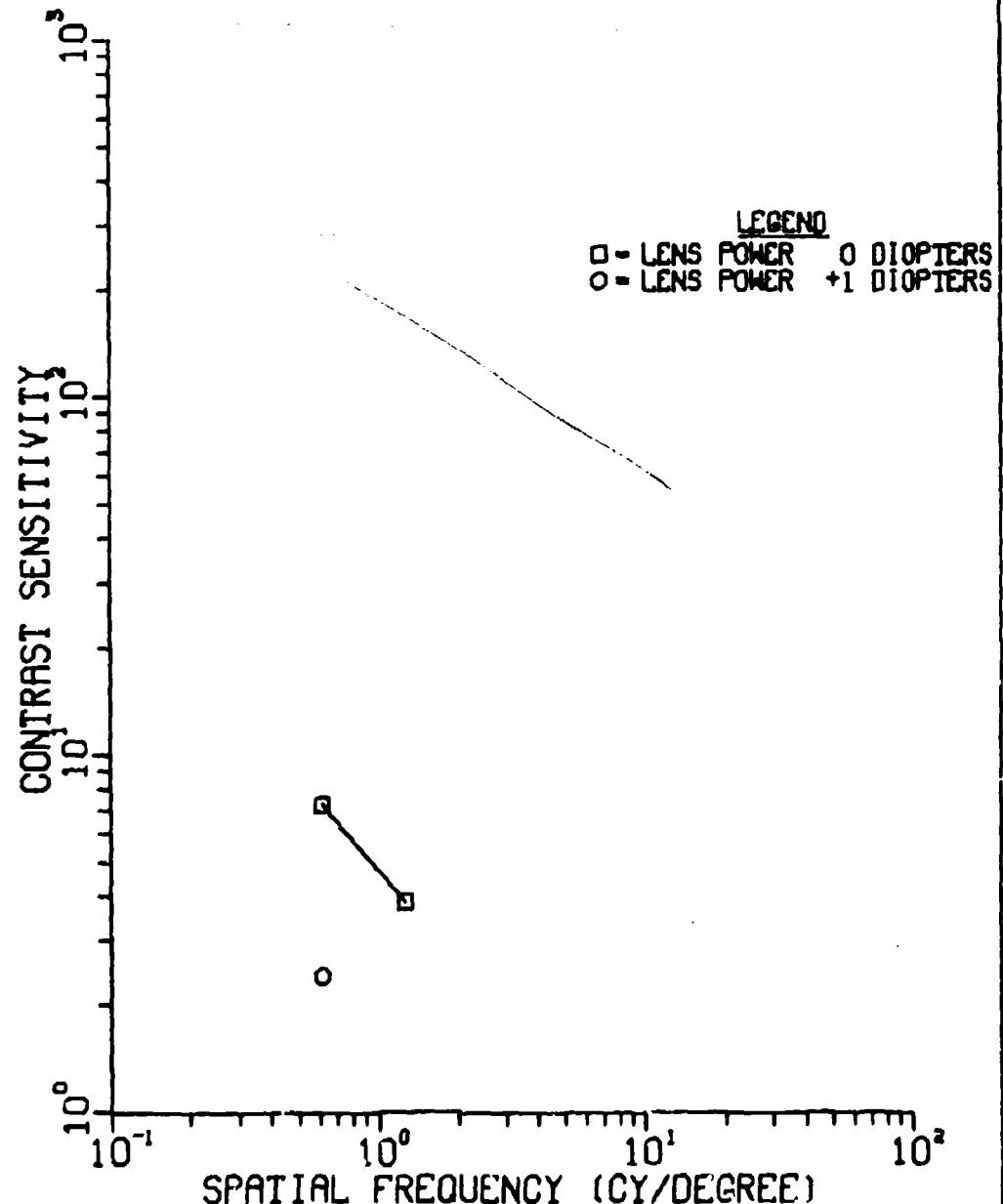


Figure 46. Identification of RA-5C for JC

DETECTION OF MIG 25 AIRCRAFT  
FOR SUBJECT JH

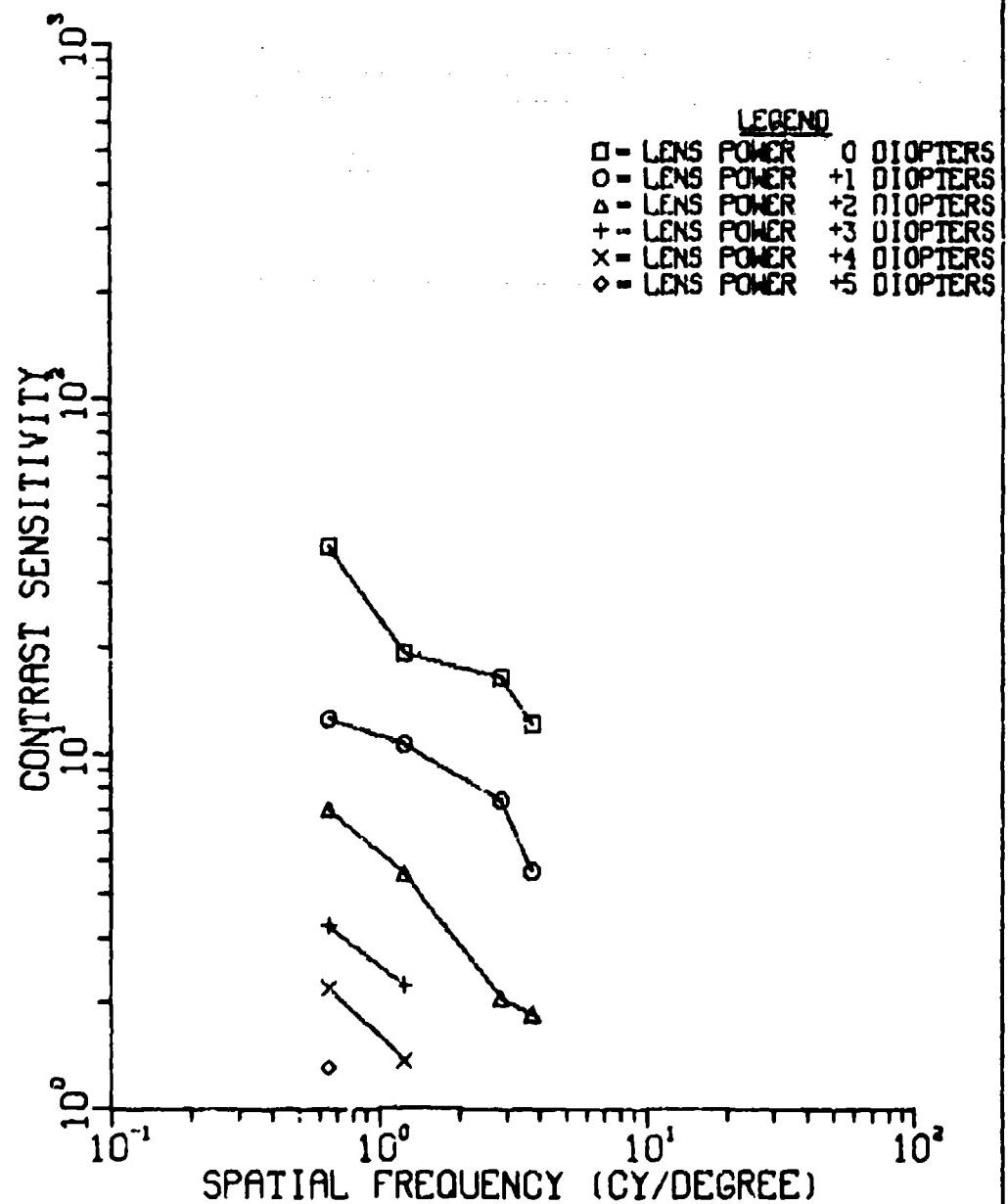


Figure 47. Detection of MIG-25 for JH

# DETECTION OF RA 5C AIRCRAFT

FOR SUBJECT JH

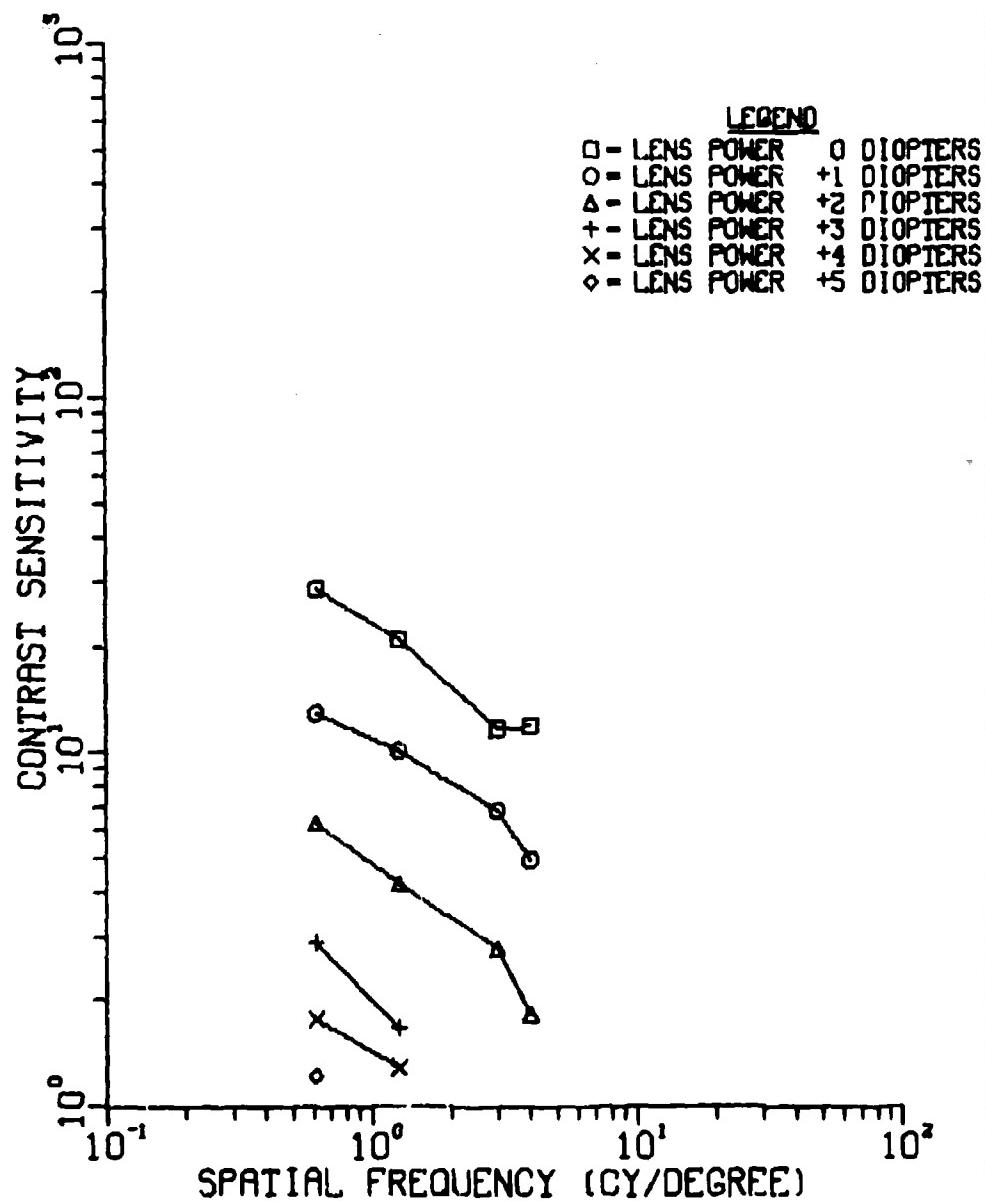


Figure 48. Detection of RA-5C for JH

# IDENTIFICATION OF MIG 25 AIRCRAFT

FOR SUBJECT JH

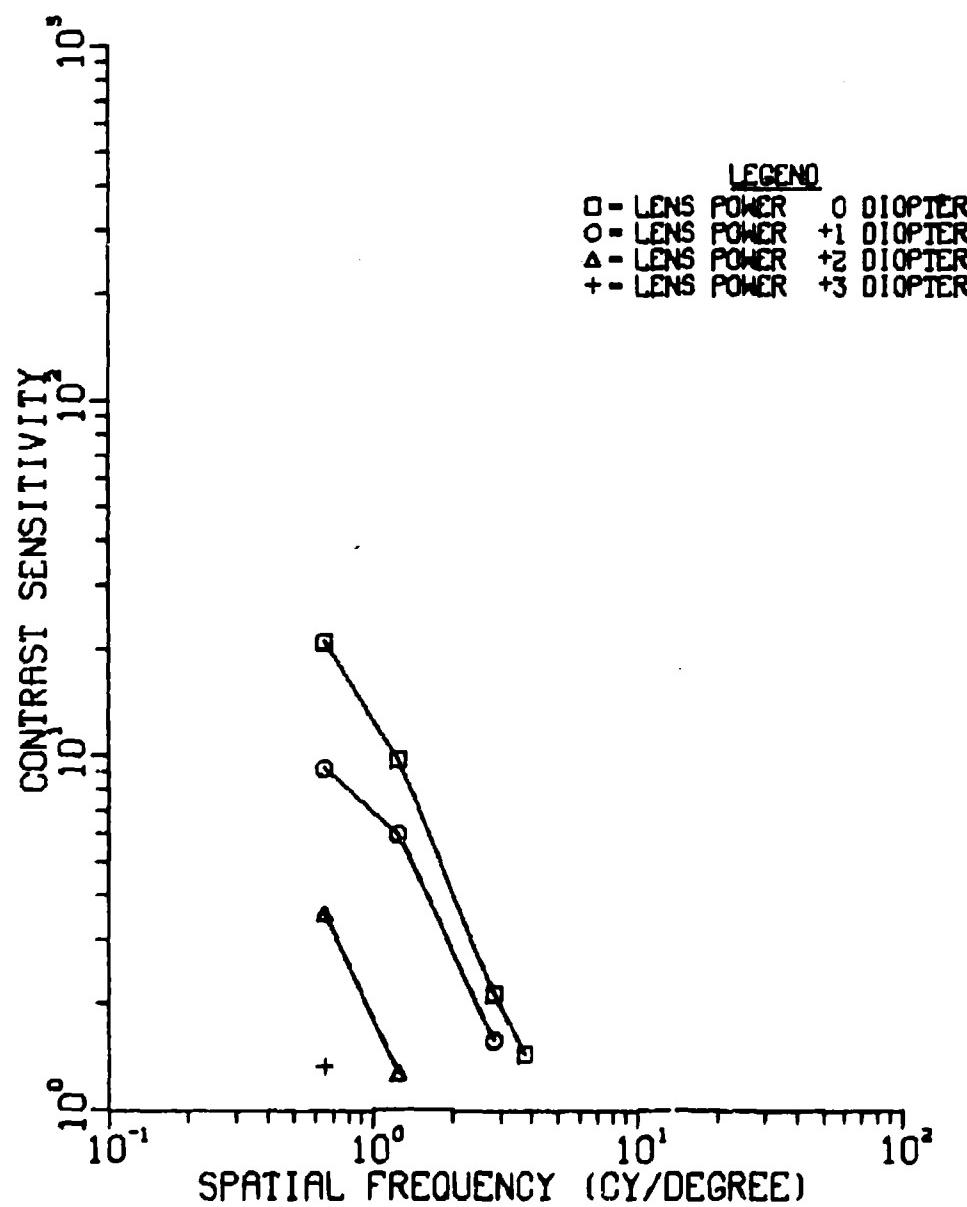


Figure 49. Identification of MIG-25 for JH

# IDENTIFICATION OF RA 5C AIRCRAFT

FOR SUBJECT JH

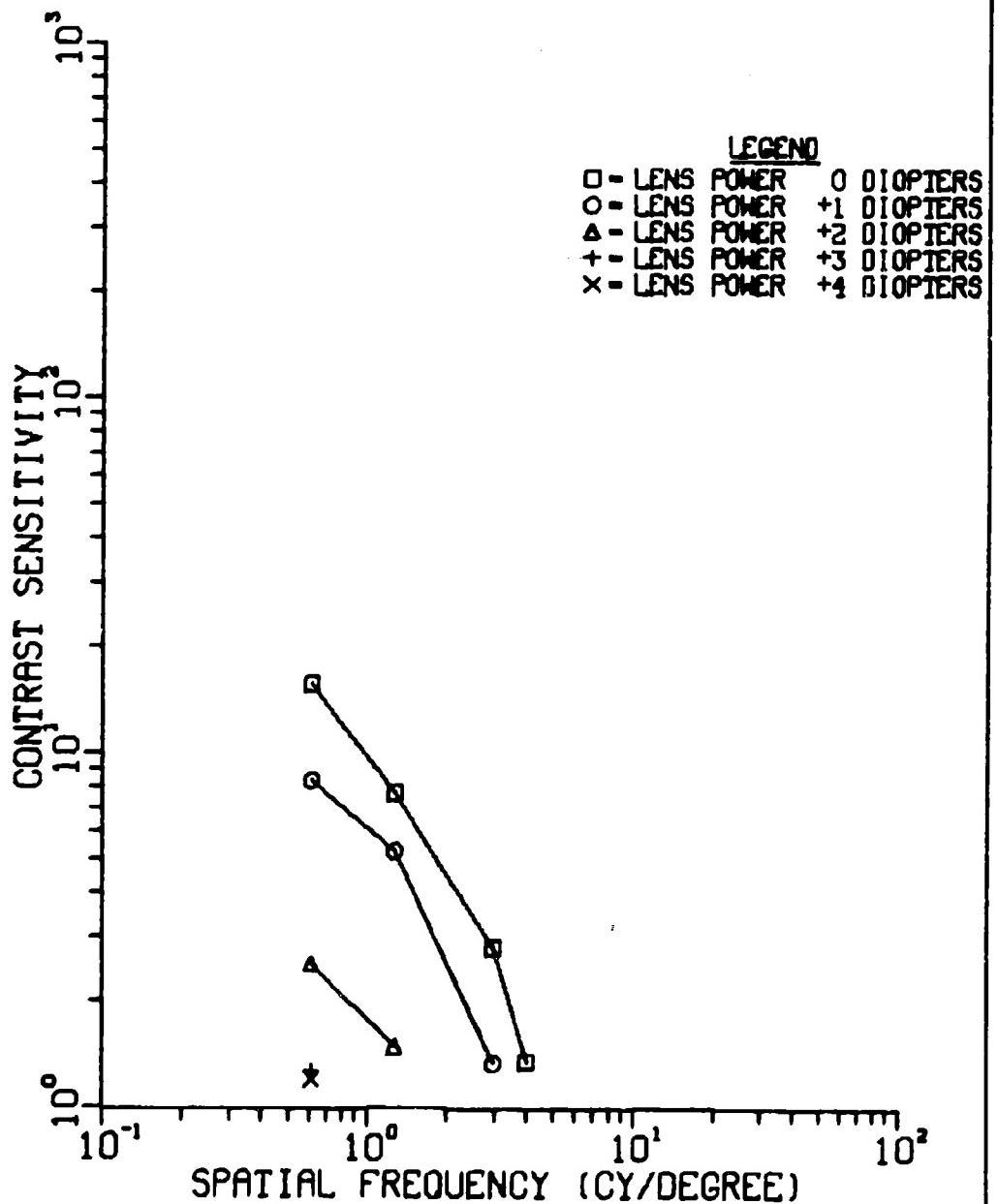


Figure 50. Identification of RA-5C for JH

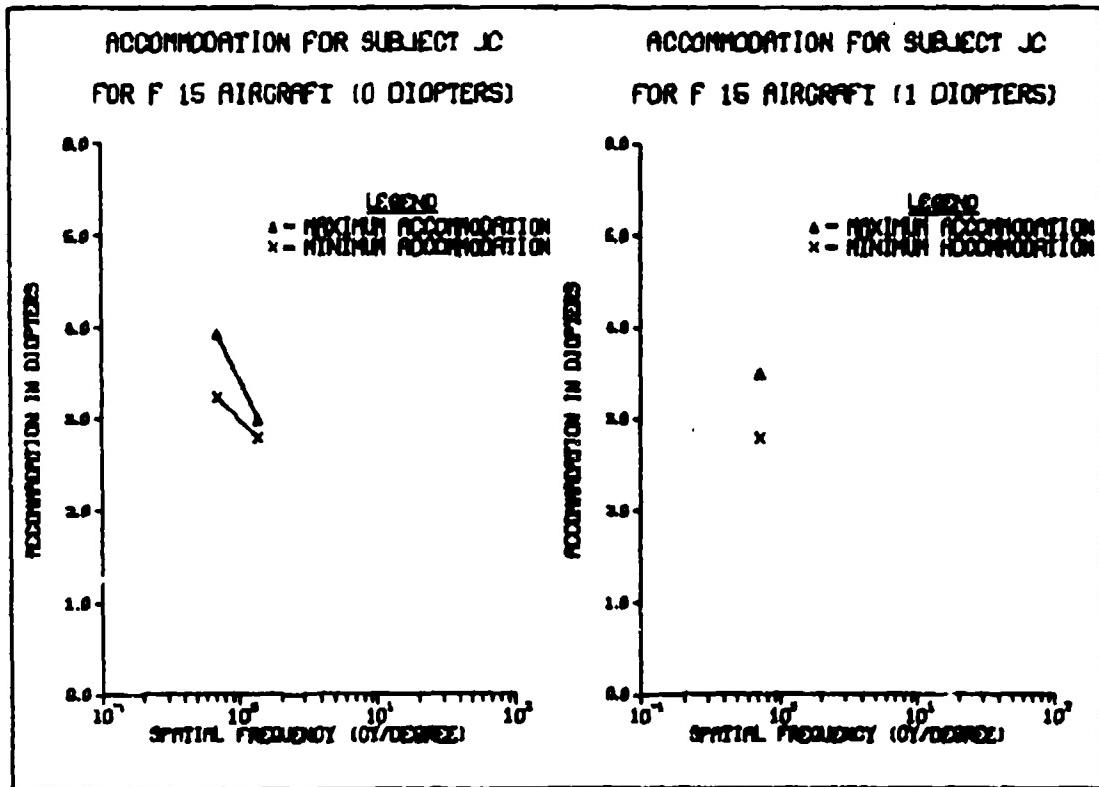


Figure 51. Accommodation for JC for F-15

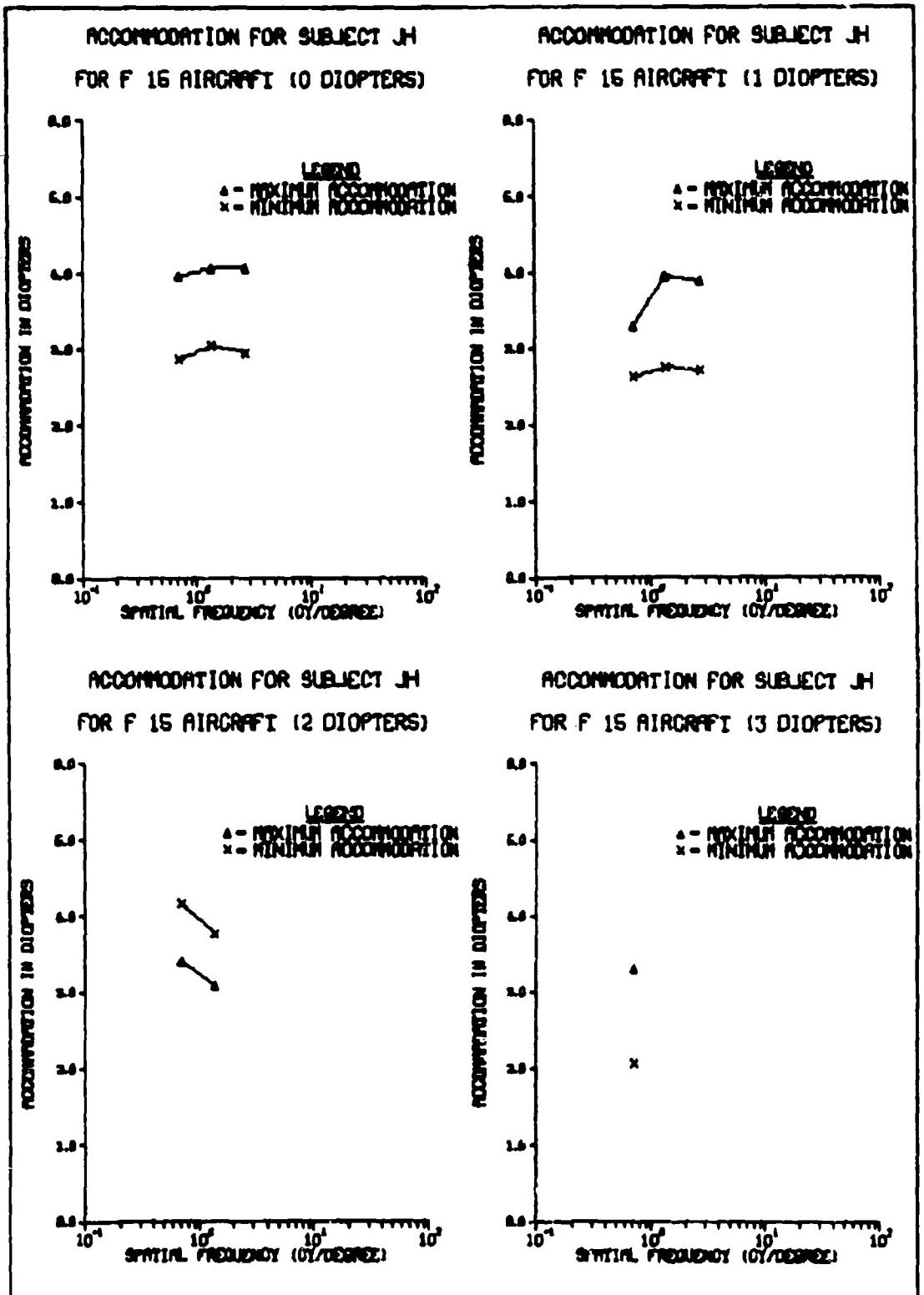


Figure 52. Accommodation for JH for F-15

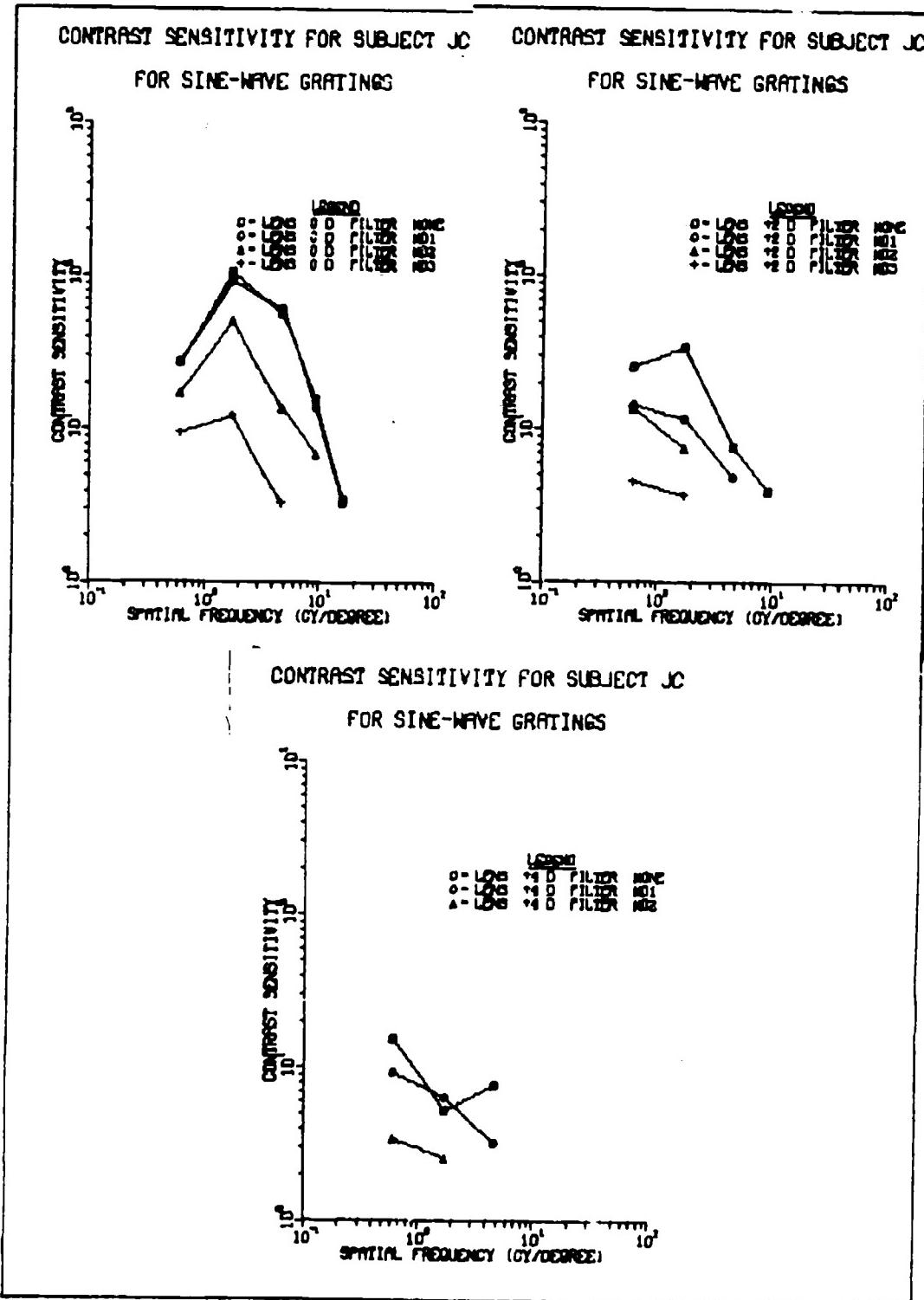


Figure 53. CSF for JC Under Low Luminance Conditions for Sine-Wave Grating Stimuli

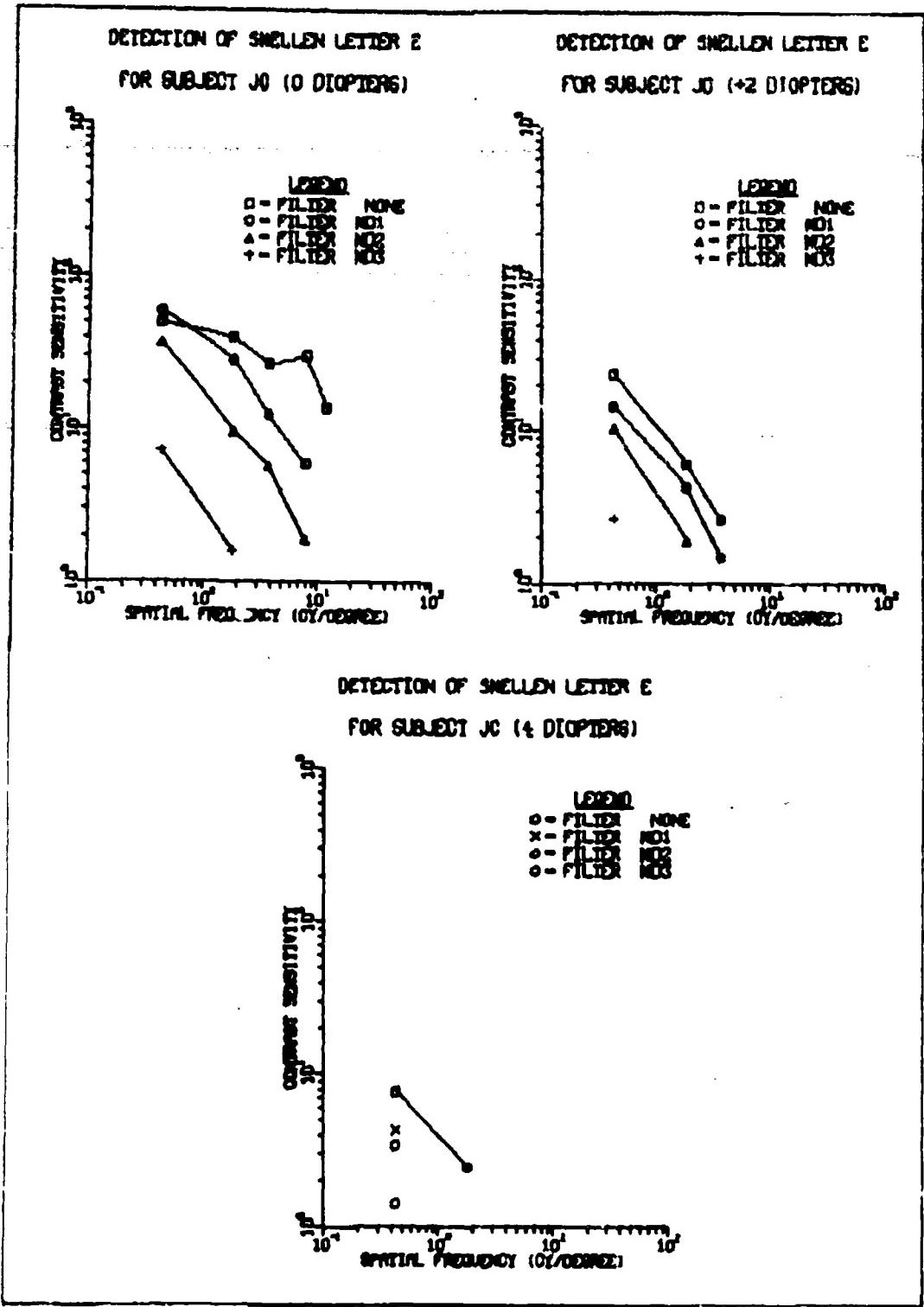


Figure 54. Detection of Snellen Letter E for JC Under Low Luminance Conditions

# DETECTION OF SNELLEN LETTER B

FOR SUBJECT JC

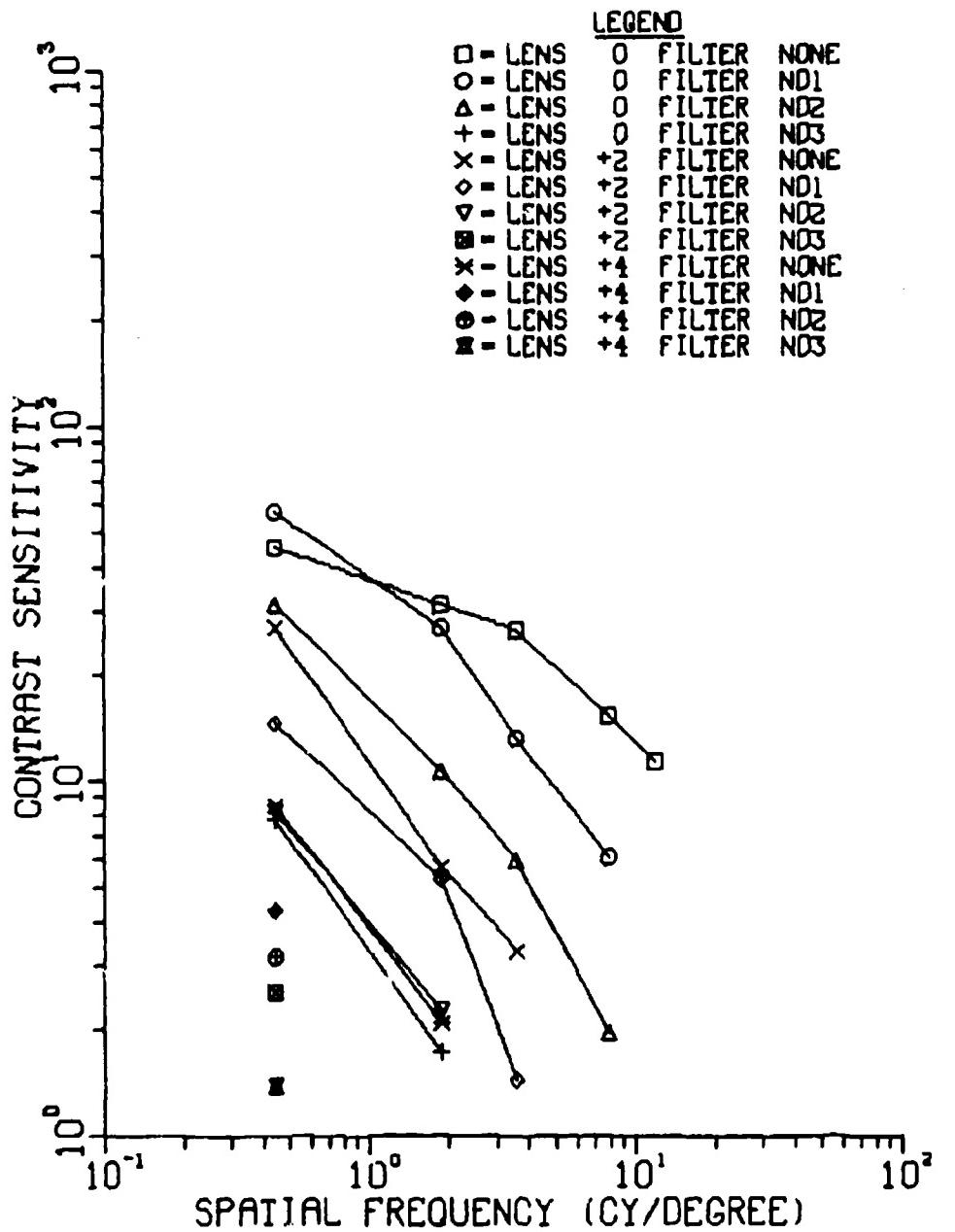


Figure 55. Detection of Snellen Letter B for JC  
Under Low Luminance Conditions

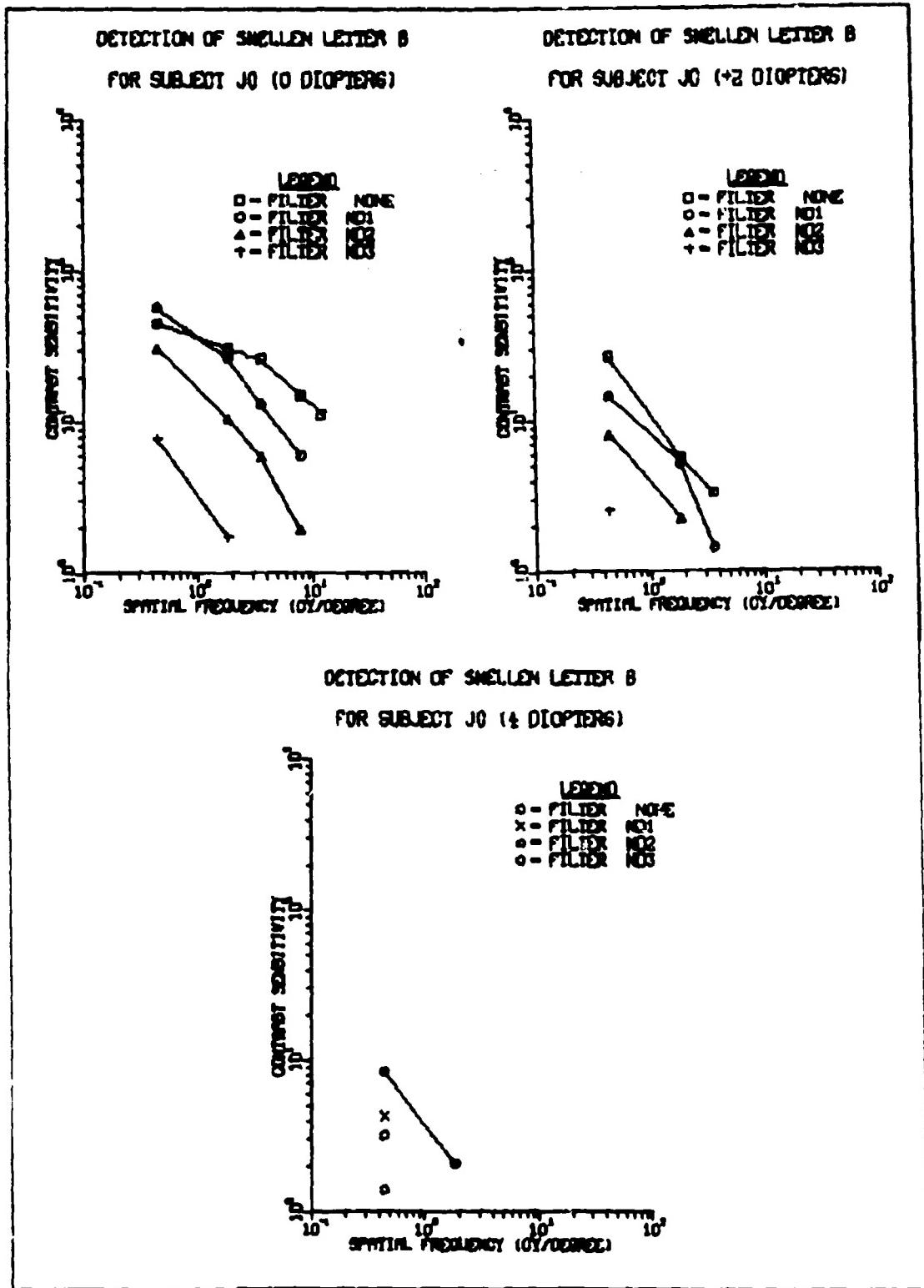


Figure 55 (Cont.) Detection of Snellen Letter B for JC  
Under Low Luminance Conditions

DETECTION OF SNELLEN LETTER E  
FOR SUBJECT JC

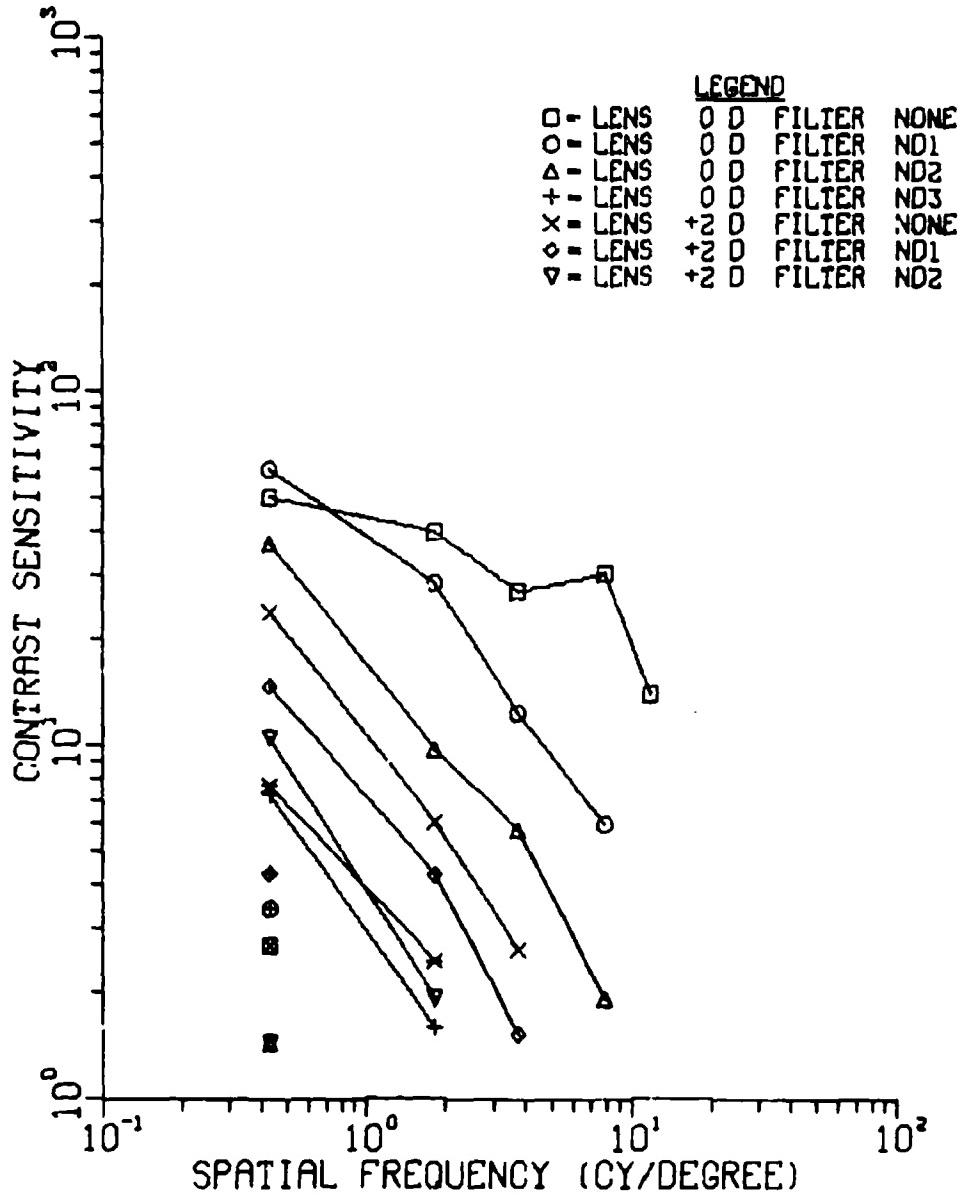


Figure 56. Detection of Snellen Letter E for JC  
Under Low Luminance Conditions

IDENTIFICATION OF SNELLEN LETTER B  
FOR SUBJECT JC

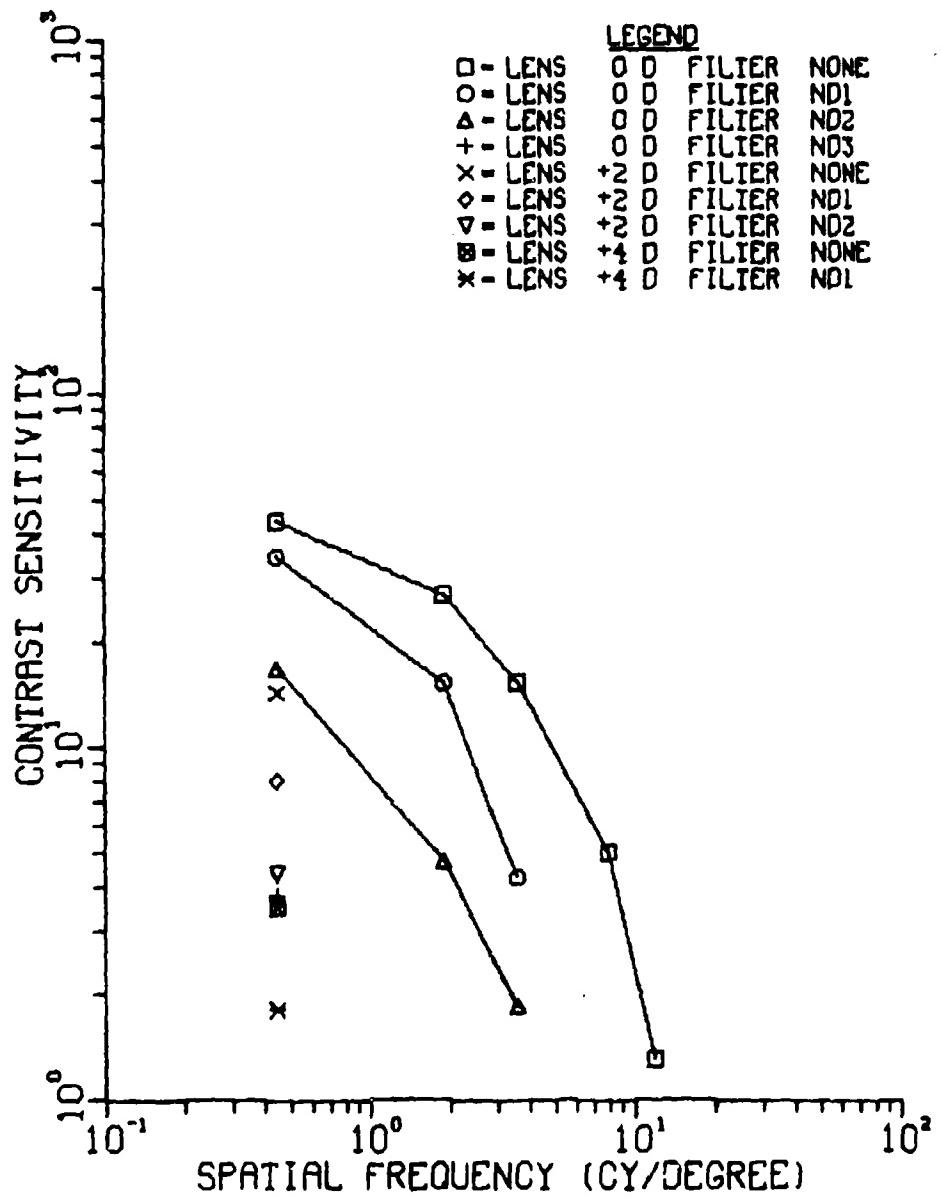


Figure 57. Identification of Letter B for JC  
Under Low Luminance Conditions

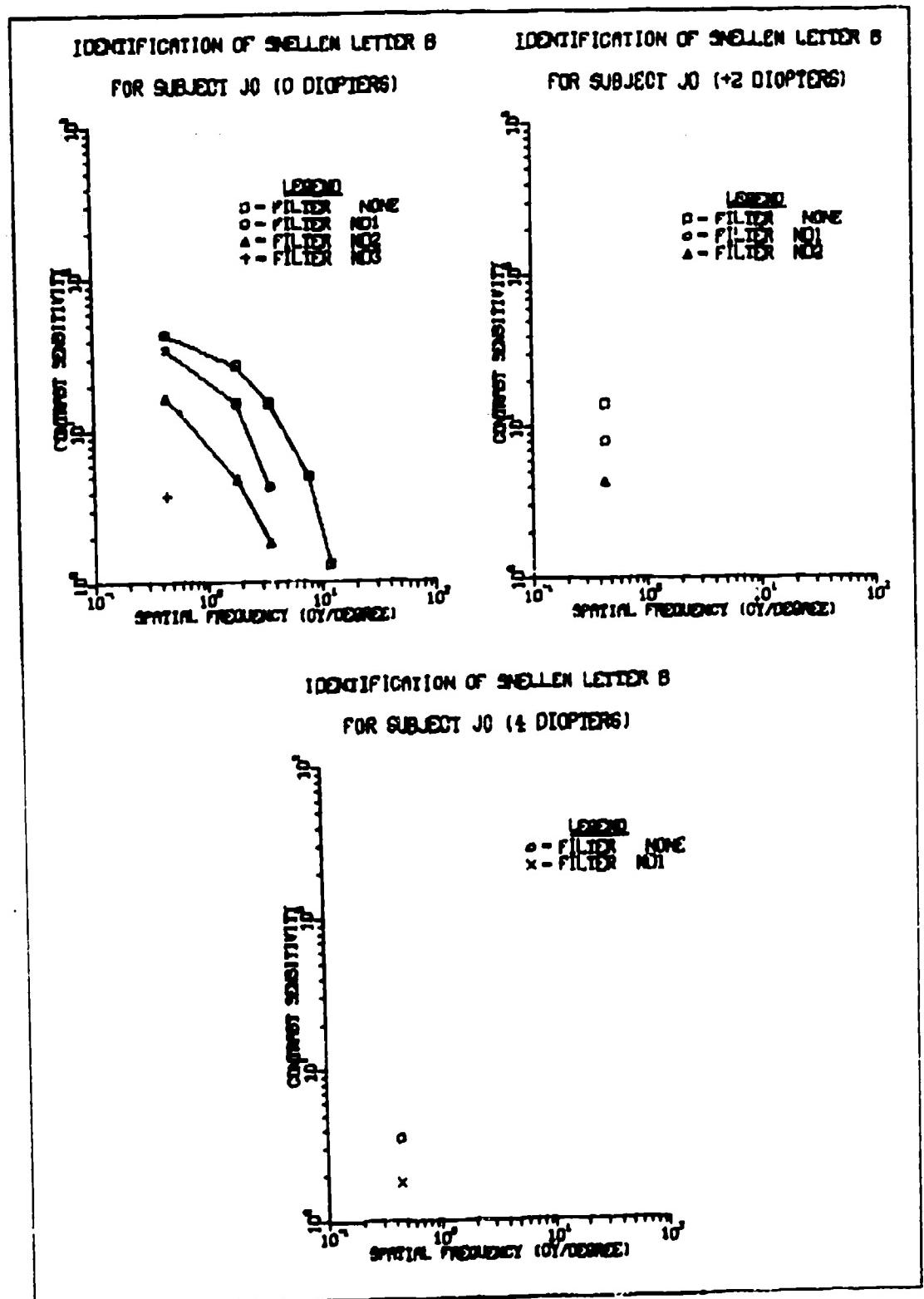
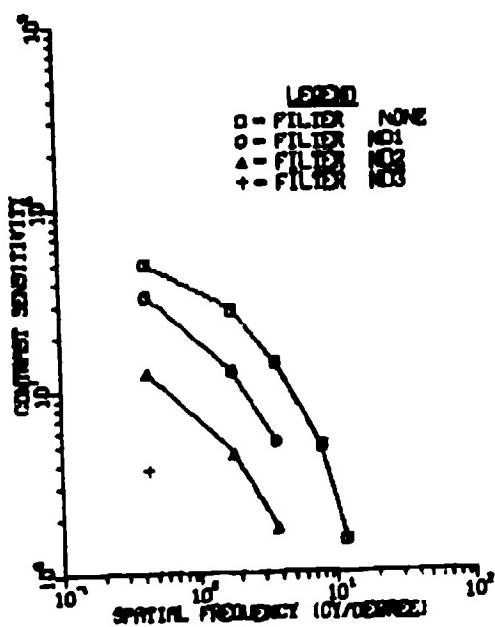


Figure 57 (Cont.) Identification of Letter B for JC  
Under Low Luminance Conditions

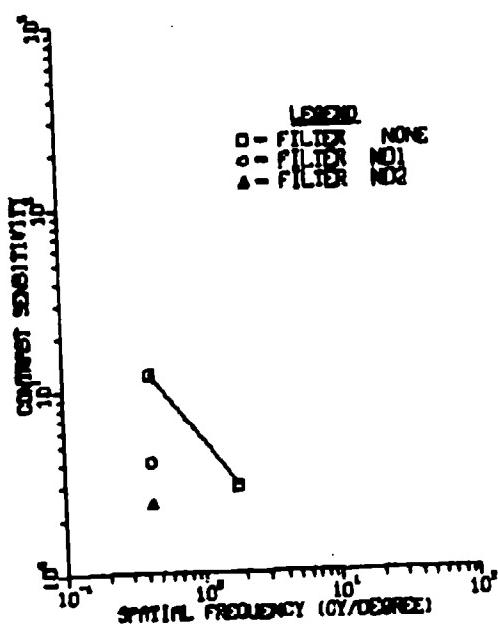
## IDENTIFICATION OF SMELLEN LETTER E

FOR SUBJECT JC (0 DIOPTERS)



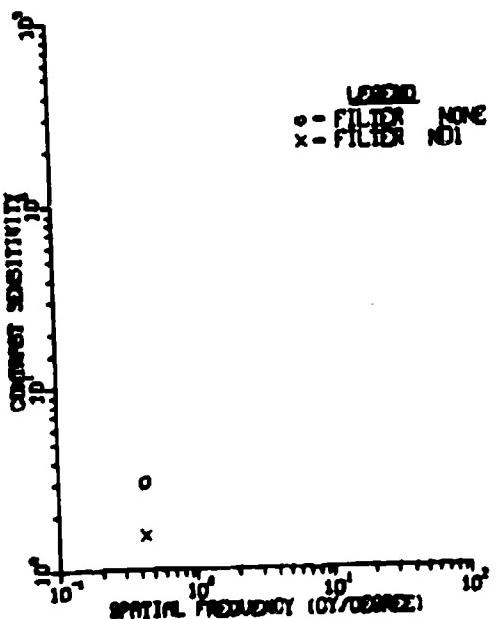
## IDENTIFICATION OF SMELLEN LETTER E

FOR SUBJECT JC (+2 DIOPTERS)



## IDENTIFICATION OF SMELLEN LETTER E

FOR SUBJECT JC (+4 DIOPTERS)

Figure 58. Identification of Letter E for JC  
Under Low Luminance Conditions

## DETECTION OF MIG 25 AIRCRAFT

FOR SUBJECT JC

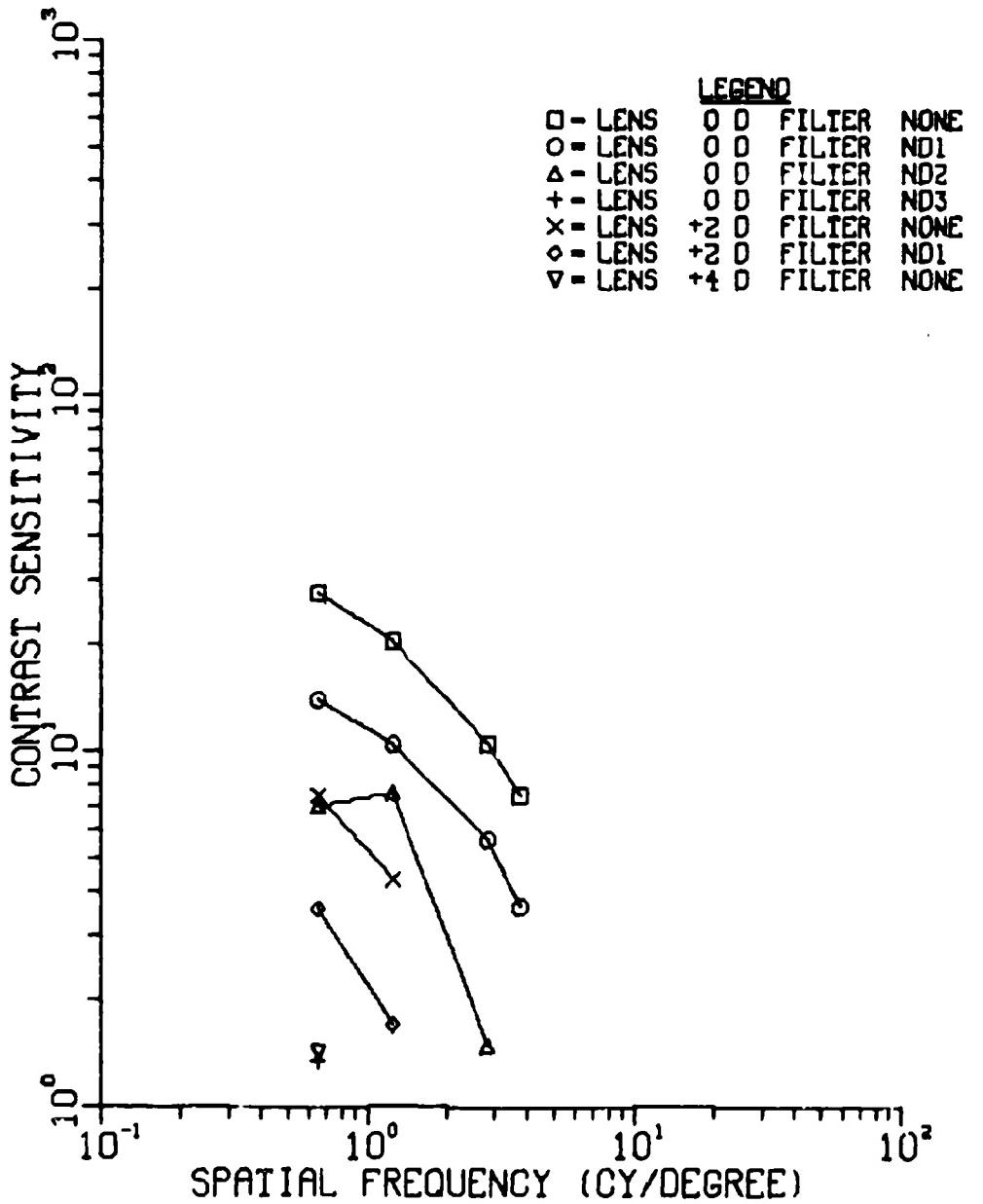


Figure 59. Detection of MIG-25 for JC  
Under Low Luminance Conditions

# IDENTIFICATION OF MIG 25 AIRCRAFT

FOR SUBJECT JC

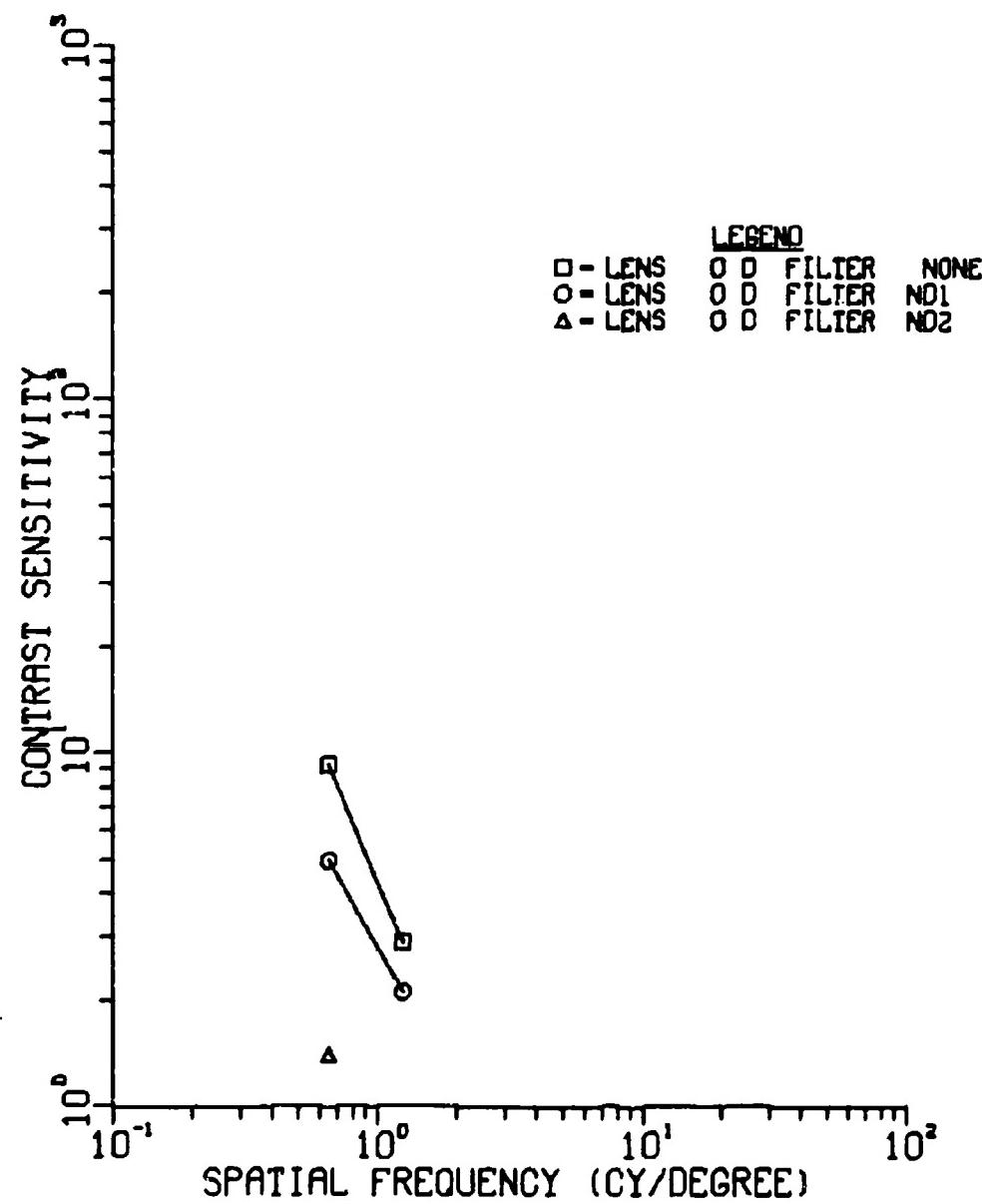


Figure 60. Identification of MIG-25 for JC  
Under Low Luminance Conditions

## VII. Vita

Julie Beth Cohen was born on 29 March 1957 in Erie Pennsylvania. She graduated from high school in Erie in 1975. She earned a Bachelor of Science in Electrical Engineering and Mathematics from Carnegie-Mellon University in 1979. Upon graduation she was commissioned in the Air Force and entered the School of Engineering, Air Force Institute of Technology. She is a member of Eta Kappa Nu and Tau Beta Pi.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/GE/BE/80D-15	2. GOVT ACCESSION NO. <i>AD-A103374</i>	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE EFFECTS OF REFRACTIVE ERROR ON THE DETECTION AND IDENTIFICATION OF SIMPLE AND COMPLEX TARGETS		5. TYPE OF REPORT & PERIOD COVERED MS Thesis
7. AUTHOR(s) Julie B. Cohen 2nd Lt. USAF	6. PERFORMING ORG. REPORT NUMBER	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Institute of Technology (AFIT-EN) Wright-Patterson AFB, Ohio 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Medical Research Laboratory AMRL/HEA Wright-Patterson AFB, Ohio 45433	12. REPORT DATE December 1980	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	13. NUMBER OF PAGES 101	
15. SECURITY CLASS. (of this report) Unclassified		
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES <i>Approved for public release; IAW AFK 190-17 Frederic C. Lynch Director of Public Affairs</i>	18. SUPPLEMENTARY NOTES <i>Approved for public release; IAW AFK 190-17 Frederic C. Lynch Major, USAF Director of Public Affairs</i>	
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Contrast sensitivity Accommodation Refractive error Low luminance		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  The effect of refractive error on the detection and identification of simple and complex targets was studied. Contrast sensitivity to sine-wave gratings of spatial frequencies from 0.61 to 22 cycles per degree with induced refractive error of 0, +1, +2, +3, +4, +5 and +6 diopters were measured. Objective subject accommodation measurements were determined. The contrast needed to detect and identify Snellen letters and		

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aircraft was also measured at the same levels of refractive error. In addition, some measurements were accomplished with reductions in the average luminance of 6 foot lamberts by factors of 10, 100 and 1000.

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